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VENUS REVEALS SECRETS

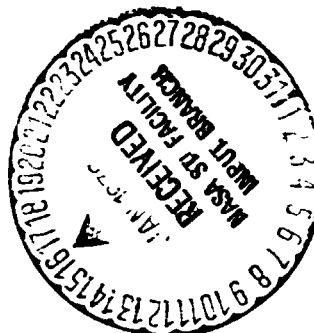
V. Alekseyev and S. Minchin

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ANNOTATION

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This book also discusses the operation of the automatic space station Venera-8, which first studied the atmosphere and the surface of Venus on the illuminated side of the planet. New scientific data obtained as the result of the flight of Venera-8 has enriched world science regarding the universe and has represented a new step in Soviet science and technology in investigating space by means of automatic spacecraft.

VENUS REVEALS SECRETS

V. Alekseyev and S. Minchin

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INTRODUCTION

The present epoch - a time of the greatest achievements in 13* natural science and technology - is characterized by the ever-increasing role of space research, which has opened up new possibilities for a more profound knowledge of nature.

The study of circumterrestrial space is accompanied by a study of deep space, human flight - with the launches of automatic stations toward planets of the solar system and the Moon.

We have become witnesses to the prophetic words of Konstantin Eduardovich Tsiolkovskiy "Mankind will not always remain on the Earth but, in the pursuit of light and space, he will first timidly penetrate beyond the limits of the atmosphere, and then will inhabit all of the circumsolar space."

Mankind is now penetrating into space, studying it, and using it for the purposes of his own interests.

The launches of artificial satellites have revealed the enormous influence of the preplanetary cosmic space upon the atmosphere and the ionosphere of the Earth, and how the processes develop in it.

The satellites of the meteorological system "Meteor" have systematically transmitted data about processes occurring in the atmosphere, and have made it possible to warn ships, aircraft, and the population of endangered regions about advancing storms, typhoons, and other natural calamities. They have made it possible to predict the weather in different regions of our planet more exactly, which is of tremendous economic importance for all countries.

* Numbers in the margin indicate pagination of original foreign text.

It has become customary for millions of people, living in very remote parts of our country to receive transmissions from the Central Television and Video Telephone Communication by means of the satellite Molniya-1, using the Earth-based network of receiving stations "Orbit." /4

The Soviet Union and the United States have carried out a large program of space research using the manned spacecraft Soyuz and Apollo and the orbital stations Salyut and Sky Lab.

Soviet automatic stations carry out systematic investigations of space.

The flights of the Soviet automatic stations Luna-9 and Luna-10 first solved the problems of a soft landing on the Moon and of producing an artificial satellite of the Moon.

The interplanetary automatic stations Zond-5, Zond-6, Zond-7 and Zond-8 were the first to return to Earth from deep space flights with results of scientific measurements onboard.

The study of the Moon and Mars has been successfully carried out by Soviet automatic stations. In September, 1970, the automatic station Luna-16 transmitted to Earth lunar soil taken in the region of the Mare Fecunditatis. In November, 1970, Lunokhod-1, placed on the Moon by the station Luna-17, passed over the first rail on the lunar surface in the region of Mare Imbrium and for 10.5 months continued scientific investigations along a 10 kilometer track. In September, 1971, the automatic station Luna-19 was launched into a circumlunar orbit, which continued studies of the Moon for more than a year. In February, 1972, the automatic station Luna-20 transmitted to the Earth lunar soil from the continent region of the Moon. Between 16 January and 17 April 1973, in the transitional sea-continent zone of Mare Serenitatis, overcoming 37 kilo-

meters of lunar soil with no roads, Lunokhod-2 placed on the surface by the automatic station Luna-21, carried out unusual investigations.

On 27 November and to December, 1971, after a 6-month space flight, the stations Mars-2 and Mars-3, and the descent capsule of Mars-3 were launched into the orbit of satellites of Mars. These were the first to land on the surface of this planet. The automatic stations Mars-4, Mars-5, Mars-6 and Mars-7 in February-March, 1973, completed a program of studies, and transmitted to the Earth unusual new data about this planet.

With the descent of the capsule, the first direct studies were made in the atmosphere of the planet.

Soviet scientists are continuing systematic studies of Venus by means of spacecraft, initiated by the automatic station Venera-4 in 1967.

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One important space experiment has been successfully completed. The automatic interplanetary station Venera-8, which was launched on 27 March 1972, has reached the planet Venus. On 22 July, the descent capsule of the Venera-8 station, after aerodynamic braking in the upper layers of the atmosphere, completed a smooth descent by parachute and a soft landing on the illuminated portion of the surface of Venus.

Pennants with a bas-relief of the founder of the Soviet State, Vladimir Il'ich Lenin, and the coat of arms of the Union of Soviet Socialist Republics were placed on the surface of the planet.

For the first time in the history of cosmonautics, scientific investigations were performed on the surface of Venus and the parameters of the planet's atmosphere on its illuminated side were determined.

New scientific data has been obtained about the properties of the surface and atmosphere of Venus. Another step in understanding the universe was taken.

On 5 February 1974, on its trajectory towards Mercury, the American spacecraft Mariner-10 flew around Venus at a distance of about 6,000 kilometers and carried out scientific studies and photographs of the cloud layer of the planet.

The program for studying the planets of the solar system by automatic stations is continuing.

The purpose of this book is to discuss the Soviet program of studying the planet Venus by means of automatic stations.

THE ENIGMATIC PLANET

... Each man has his stars. For some who are wandering, they show the path. For others, these are simply small lights. For scientists they are a problem which must be solved.

/6

Antoine de Saint Exupery

Venus in its mysterious, alluring light appears in the sky to the observer on Earth in the evening in the West, then in the morning in the East, but never at night. Therefore, the ancients assumed that this was two stars: in the evening Vesper, and in the morning, Lucifer. However the ancient scientist Pythagoras knew that in actuality this was one star. It received the name of Venus - one of the goddesses of Roman mythology - the goddess of beauty. Due to its brightness and unusual color, it has been affectionately called Little Evening.

To designate the Sun, the Moon, and the planets the astronomers have used the signs of ancient origin. The sign of Venus is the image of a hand mirror - the emblem of life and beauty.

Performing optical observations of Venus, scientists have established that it moves around the Sun on an almost circular orbit at an average distance from it of 108.2 million kilometers. Its complete revolution around the Sun requires 224 days, 16 hours, 49 minutes, and the average orbital velocity is 35 kilometers per second. The apparent radius of the planet has been estimated as approximately 6100 kilometers. Knowing these values, and also the perturbations caused by Venus in the motion of other celestial bodies, scientists have calculated its mass - 0.8136 the mass of the Earth, and the average density of the matter of Venus - 5.12 grams per 1 cubic centimeter.

(Caption page 7): View of Venus in the telescope at different phases (western elongation).

Venus is the closest planet to us. Along its orbit, it periodically occupies two diametrically opposite positions with respect to the Sun and the Earth; these positions have been called the inferior conjunction, when Venus is between the Sun and the Earth, and the superior conjunction, when the Sun is between the Earth and Venus. Thus the minimum distance between Venus and the Earth is about 42 million kilometers (inferior conjunction) and the maximum distance is 258 million kilometers (superior conjunction).

The period between two inferior conjunctions - called the synodic period - is 584 days. This is explained by the fact that in one day Venus passes over $1/225$ portion of its orbit, and the Earth - $1/365$. Consequently, in its orbital motion in one day Venus exceeds the Earth by $1/584$ portion of a circle. 17

The mutual position of the Earth, Venus, and the Sun in the inferior conjunction, when they are located on one line, changes when Venus passes through the disc of the Sun. This may be observed even by an untrained eye. However, this phenomenon may not be seen by every onlooker, since the periodicity of Venus is 8; 105.5; 8 and 121.5 years. In the past century this phenomenon was observed on 9 December 1874, and 8 December 1882. Only on 8 June 2004 and 6 June 2012 will it be repeated again.

In 1610 Gallileo, observing Venus in a telescope, first observed and described the consecutive changes in its phases, similarly to the Moon. He was not first convinced of the validity of his observations, and decided not to report on it openly. Therefore, information about this discovery of Gallileo was recorded in a Latin phrase anagram and only later, finally convinced of its correctness, was it deciphered and represented by the words "the mother of love

imitates the forms of Cynthus." The mother of love is the goddess Venus, and Cynthus is one of the old names of the Moon.

In the inferior conjunction, when Venus is at the closest distance to the Earth, its nonilluminated side is always turned toward the Earth, and therefore its largest phase cannot be seen at all. When deviating from this position of the "new Venus", the planet assumes the form of a sickle, whose diameter is smaller, the wider the sickle. The complete disc of Venus can be seen at an angle to the Sun of 10° , and the largest sickle - at an angle of 64° .

In 1761 the first Russian academician Mikhail Vasil'yevich Lomonosov, observing Venus as it passed along the solar disc, established that at the beginning of its motion, when only a small portion of Venus was turned toward the Sun, on the side of the dark background a bright ring emerged around the remaining disc of the planet. With its further motion, when Venus completely covered the disc of the Sun and moved to the opposite edge by $1/10$ of its diameter, a "bubble" was observed at the edge of the Sun, which first increased, and then disappeared together with a small segment of the planet disc. Similar phenomena were observed by Lomonosov when Venus merged with the Sun. /8

In addition, Lomonosov noted that at the moment of external and internal "contact" of Venus and the Sun, the edge of the Sun became unclear and both discs seemed to merge.

At first Lomonosov explained these phenomena by the presence of a powerful atmosphere on Venus, more precisely, the phenomenon of refraction which occurred when the solar rays passed through the dense atmosphere of Venus.

Lomonosov described his observations in "The Phenomenon of Venus on the Sun, Observed in the Saint Petersburg Royal Academy

(Caption page 8): Passage of Venus along the solar disc (according to photographs of M.V. Lomonosov).

of Sciences on 26 May 1761," as follows: "When the leading edge of Venus approached the edge of the Sun and was about $1/10$ of the Venus diameter, a bubble appeared at the edge of the Sun, which clearly became longer, the closer Venus came to the protuberance. Suddenly the bubble disappeared, and Venus rapidly appeared to have no edge." In addition: "Based on his observations Lomonosov believes that the planet Venus is surrounded by a dense atmosphere of air which appears to be like that (provided that it is not large) surrounding our planet Earth."

The discovery of Lomonosov confirms the figure which he had drawn during observations of the passage of Venus and the passage /9 of the solar rays through the atmosphere of Venus. Let us examine this figure. The quantity LO is a ray passing from the Sun to the observer when there is no atmosphere; $LdhO$ - a ray passing from the Sun to the observer when there is an atmosphere on Venus. This ray will have double refraction at the points d and h at the boundary of the atmosphere. Thus we may arbitrarily assume that at these points the density of the medium changes sharply.

As a result of this, the observer will see the point L on the continuation of the ray OhR .

Consequently, the edge of the Sun will appear to the observer to be shifted (formation of the "bubble").

The phenomenon by which Venus is covered by the stars is observed much more frequently than the passage of Venus over the solar disc. Many astronomers have investigated this phenomenon, which makes it possible to continue the study of Venus.

Observing the covering of Venus by the stars Regulus, the constellation Gemini and others, scientists have noted that the stars did not appear simultaneously from the disc of Venus, as occurs when these stars are covered by the Moon.

At first a great brightness appeared, then a small star which was not very bright separated from the dark edge of the planet, but after 1.5 - 2 seconds the brightness of the star almost reached a maximum. Then, as the surface of Venus receded, the brightness continued to increase.

They explain this phenomenon, just like Lomonosov, by the presence of an atmosphere on Venus, which - according to their calculations - must have a thickness from 80 to 110 kilometers.

The atmosphere of Venus proved to be so "strong" that even powerful optical telescopes could not penetrate the dense cloud cover, which hides its face from us. That is why for a long period of time we did not know the rate at which Venus rotates around its axis, the temperature, or the aggregate composition of its surface - hard stones, water surface, or molten lava? Scientists could not satisfactorily answer the question of the planet relief.

Only unclear dark or light spots could be observed visually or by photographs on the disc of Venus. They had a varying form and were observed for several days or weeks. Some of them were unstable and after two or three days after they had appeared would disappear from the bright background of the planet. However, stable spots of large dimensions were encountered frequently.

New methods of studying the planets of the solar system arose with the development of science and technology: the methods of spectrography, radioastronomy and radar.

Spectrometric investigations and radio observations represented a new stage in the study of Venus. This was because they could be used to obtain new data about Venus which had been reliably hidden from the observers by a dense atmosphere.

During its development, optical astronomy passed from the telescope of Galileo to the present day extremely complex optical devices - refractors, reflectors, and mirror-lens systems.

A refractor is a telescope in which the image of celestial stars is produced by the refraction of light rays in the lens objective. This image is examined through the eyepiece, photographed, and studied by means of a spectrograph, photometer, etc. /10

The resolving capacity of the telescope is larger, the greater the diameter of the objective. However, the thickness of the lenses comprising the telescope objective increases simultaneously with a diameter increase, and consequently the light absorption in the lenses increases.

Due to this, objectives with a diameter more than one meter barely increase the resolving capacity of the refractors. In addition, refractors have the following great disadvantages: chromatic aberration (coloring of the image) and spherical aberrations (scattering of light by the lens edges). For these reasons, reflectors are widely used at the present time.

A reflector is a reflecting telescope. Its basic parts are the concave mirror (main mirror) and ocular.

The dimensions of the main reflector mirrors greatly exceed the diameters of the refractor objectives, and thus the resolving capacity of the reflectors is high.

At the present time the Mount Palomar Observatory in the United States uses a reflector whose main mirror diameter equals 508 centimeters.

In recent years, new equipment for optical astronomical observations has been developed and produced - television and electron telescopes.

The name of the telescopes - television and electron - is not quite valid. Systems of these types cannot be used independently, but in combination with optical telescopes. Consequently, these systems are complex receivers (detectors) of radiation, and not independent telescopes.

Television and electron telescopes represent refractors or reflectors in whose focus there is a transmitting television tube (in a television telescope) or an electron-optical transformer (in an electron telescope), which convert the infrared image of the object into the visible image, or simply the electron image amplifier.

Optical observations performed by observatories have a direct dependence on the state of the atmosphere. Cloudiness, rain, snow, fog, high turbulence of the atmosphere, dust in the air and sharp temperature drops - all of this makes it difficult to perform studies. Therefore, at the present time, as a rule, attempts are made to place observatories high in the mountains or in regions with a dry climate and a great number of clear days during the year.

Recently astronomers have placed on airplanes and balloons astronomical equipment in the upper layers of the atmosphere. Using rockets and spacecraft, they have sent astronomical instruments beyond the limits of the atmosphere. As a result of the observations using the new technology, it has been possible to greatly extend our astronomical knowledge, using for the observations wave-

length ranges which are not permissible for investigations on the Earth.

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Studies of ultraviolet and x-ray radiation have been made using rocket probes. Small and low-inertial equipment has been used to record this radiation.

Balloons are more suitable for studying the infrared spectroband. In the first place, they can be used to raise comparably large telescopes and spectrometers to an altitude of more than 25 kilometers, leaving below 99.9% of all the water vapor, and sharply decreasing the transparency of the terrestrial atmosphere for infrared emission. In the second place, the velocity of the air streams at great altitudes is low. This makes it possible to perform observations from an almost unmoving balloon for a long period of time, which is necessary in order to record the radiation of large wavelengths.

Highly accurate experiments on spectroscopy of Venus and other celestial bodies have been performed using telescopes having spectrometers and Fourier spectrometers, placed on balloons to the upper layers of the Earth's atmosphere.

Carbon monoxide CO_2 was discovered in 1932 in the upper atmosphere of Venus over a cloud layer. Many scientists assumed that its concentration was no more than 5 - 10%, and that the basic component of the planet's atmosphere, by analogy with the terrestrial atmosphere, was nitrogen. However, nitrogen was not found. Later, in the sixties, it was established that there was hydrogen chloride and hydrogen fluoride HCl and HF , carbon monoxide CO_1 , oxygen O_2 , water vapor, and certain other compounds. The presence in the atmosphere of Venus of hydrogen chloride and hydrogen fluoride, carbon monoxide, and other compounds may point to active volcanic activity on the planet. However, the percentile content of gasses comprising the atmosphere, and the composition of the cloud layer of the planet,

which reflects the solar light very well and makes this planet clearly visible on the night sky (in addition to the Moon) remained unknown.

Several hypotheses were advanced regarding the composition of the cloud layer during the spectrometric investigations of Venus. Some researchers stated that the cloud consisted either of water vapor, or of ice crystals. Others stipulate that these are crystals of carbon monoxide. The third group of researchers states that these are small particles of ammonium hydroxide NH_4Cl ; the fourth group assumes that these are dust clouds which have risen above the planet's surface with the powerful convective streams. The assumption has very recently been advanced that a possible component of the clouds may be partially hydrated ferrous chloride $2\text{H}_2\text{O FeCl}_2$.

Radio astronomy, as a new method of studying the universe and as a new direction in science, arose at the beginning of the thirties of this century.

The Moon, the planets, stars, the galaxy and interstellar space to a certain extent emit radio waves which have almost every possible frequency. For example, the Sun emits millimeter, centimeter, decimeter, meter, decameter, etc. radio waves, i.e., radio waves of practically any frequency, streams of which arrive at the Earth from all points in space. The radiation bands, the magnetosphere, and the terrestrial atmosphere screen the surface of the Earth from the radiation coming from the depths of space. This /12 has both a positive and a negative side. On the one hand, this saves organisms which develop on the Earth. On the other hand, the atmosphere blocks a large portion of the emissions from space, which could provide man information about space. Nitrogen, oxygen, and ozone in the atmosphere absorb ultraviolet radiation and x-rays, thus screening the Earth from the hard components of the short-wave portion of the electromagnetic spectrum of the Sun. In addition

to this, water vapor and carbon dioxide absorb the long wave portion of infrared radiation emitted by the Earth, and thus protect the surface of the Earth from extreme cooling. Along with this, water vapor, carbon monoxide, and ozone in the atmosphere intensively absorb the infrared radiation of the Sun (partially passing radiation in the wavelength range from 8 to 13 microns) and thus protect the Earth from overheating.

Consequently, out of the entire spectrum of electromagnetic waves examined, the Earth's surface is reached by waves of an optical range from 0.3 to 2.5 microns, waves of the infrared range from 8 to 13 microns, and radiowaves from 10^3 microns (millimeter waves) to $2 \cdot 10^7$ microns (20-meter waves).

Thus, for waves close to 10^4 microns, the change in the "transparency" of the atmosphere from rain, snow, and fog is very great. Waves of more than $2 \cdot 10^7$ microns are reflected from the ionized upper layers, and do not penetrate through the atmosphere. Thus, out of the total spectrum of electromagnetic waves which we know, only a comparatively small segment may be used for astronomical investigations.

Radioastronomy observations may be carried out in a very wide region independently of the state of the atmosphere and visibility conditions in the daytime or at night. Optical observations, as was indicated above, are only possible in cool weather, primarily at night.

Radiowaves are slightly absorbed by gas and the interstellar dust matter. This makes it possible for us to study more comprehensively and in greater detail our stellar system - the galaxy, a large portion of which is hidden for visual observations by dark clouds of interstellar dust.

Important astronomical quantities characterizing any celestial body are: dimensions, distance from the Earth at each moment of time, orbital velocity of motion, direction of rotation around its axis, temperature of the surface and the atmosphere, and gas composition of the atmosphere.

Radioastronomy is getting definite answers to many of the questions formulated. A study of celestial bodies may be made in active and passive regimes. In passive studies, we "listen" to radio signals coming from a terrestrial body, compare them with a standard, and - after analyzing the material obtained - establish the parameters in which we are interested.

With the active method - radar - we transmit a radio signal at a specific wavelength and a specific power to the body being studied. After receiving the reflected radio signal and analyzing it, we also obtain certain information about the celestial body. /13

Both methods are different and supplement each other.

The first radar observation of Venus was made in the United States in 1968. However, the reflected signals were very weak, and the experimental results were not very reliable.

The first successful radar observations of Venus were performed by Soviet scientists in 1961. After sending a "portion" of radio signals by means of transmitting equipment and a directional antenna, they changed to receiving the reflected signal, using the same antenna and radio receiving equipment. Knowing the propagation velocity of the waves, the direction in which the signal was sent, and determining the Doppler shift of the signal frequency from different edges of the planet, they measured the distance to the planet, the velocity at which it moved along its orbit, the velocity and direction of rotation, and the "roughness" of the planet's surface.

Under the program for international cooperation for radar observations of Venus, observations were performed using the Soviet transmitting antenna of the Center of Deep Space Communication located in the Crimea, and the radio telescope of the Jodrell Bank Observatory (England), which were located at a great distance from each other. The main parameters of Venus were determined in 1961, but with greater accuracy. These experiments were performed in 1965-1966. Radar observations of Venus and other planets, as well as the Moon, are being successfully continued at the present time.

The basic equipment for radioastronomy observations are an antenna and radio receiver, which are together called a radio telescope.

The receiving antenna and the radio telescope receiver differ from the antenna and receiver of the ordinary radio broadcast. This difference lies in the fact that the antenna of the existing receiver receives a comparatively strong signal, and for its receipt, it is sufficient to have a small antenna, a simple receiver, sometimes even a detector receiver. The situation is different with radio signals from space. They are very weak, and to receive them it is necessary to have large antennas and very sensitive receivers.

To increase the dimensions of the antenna (and increase the resolving capacity) and to increase the sensitivity of the receiver, along with receiving a small useful signal, the receiver also receives a large amount of radio interference coming from all sides which block the weak cosmic noise (the signal which is useful for radioastronomy). In order to get rid of the noise, directional antennas were developed and produced, which received predominantly radiowaves moving in a certain direction. The principle underlying the construction of the radio telescope antenna is very similar to the principle for the optical telescope.

In order to increase the resolving capacity of radio telescopes, two methods exist - decreasing the wavelength and increasing the telescope diameter. However, we are not free to select the wavelength; it is determined by the purpose of the study. In addition, the shorter the wavelength, the greater care must be used in manufacturing the telescope surface, and the more difficult it is to produce the receiving devices. The best variation is large diameters of telescopes with a surface making it possible to operate at all wavelengths of the radio range.

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However, with an increase in the diameter the cost of the telescope increases, a third or even more than its dimensions. In addition, the technical difficulties connected with manufacturing such telescopes increase by several factors.

There are now several different types of radio telescopes; parabolic antennas, cophasal antennas, variable profile antennas, the Mills cross, and interferometers are being very widely used.

An interferometer consists of two or more radio telescopes of comparatively small dimensions, which are far apart and connected by a high frequency cable.

The resolving capacity of an interferometer is determined, not by the diameter of the radiotelescopes it contains, but by the distance between them.

An example of an interferometer consisting of 8 16-meter parabolic antennas is the antenna of the Center of Deep Space Communication of the Soviet Union. An example of a parabolic antenna is the large radio telescope with a diameter of 76 meters in the Jodrell Bank Observatory (England), used for investigations by the well known English scientist Lowell. These devices can be turned in the necessary direction with great accuracy in terms of

elevation and azimuth, and they can follow the motion of interplanetary automatic stations and celestial bodies. As a rule, radio telescopes operate in two modes: receiving and transmittal.

As was indicated above, successful radar observations of the Moon and the planets were initiated in the United States, USSR, England, and other countries almost simultaneously in 1961. The results of the first measurements of the velocity of rotation of Venus were different and were estimated at 100 to 400 days.

More accurate and comprehensive data were obtained by measurements of the signal reflected from Venus carried out in 1962 and 1964 near the inferior conjunction of the planet. It was established that the best agreement between the calculated and experimental data occurred with inverse revolution of Venus with a period of 230 ± 25 days. A comparison of the results of measurements in 1962 and 1964 showed that the axis of rotation of Venus is almost perpendicular to the plane of its orbit.

Radar investigations of recent years using improved and more accurate equipment have established that the period of rotation of the planet is 243.1 ± 0.2 terrestrial days (retrograde rotation), and the radius of the solid body of Venus is 6052 ± 2.5 kilometers.

Knowing the period of rotation and the period of revolution of Venus, the duration of Venus days was found to equal 117 terrestrial days. During a year on Venus, an observer can see two settings and risings of the Sun.

An analysis of the signal reflected from the surface of Venus also shows that the surface of Venus is relatively smooth. The diameter of the central reflecting spot is 1800 kilometers (about 15% of the total diameter, whereas on the Moon it is 10% of the total diameter). The smoothness of Venus for the radio range is some-

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what less than that of the Moon; slopes of up to 10-15° are possible.

However, it is not only these data which have interested astronomers. The question has arisen: is it not possible to use radio astronomy to penetrate the cloud covering and to determine the surface temperature of the planet?

During measurements of the brightness temperature of Venus during its different phases in the region of the inferior conjunction, it has been shown experimentally that the rotational direction of Venus is the opposite of that of other planets. In the case of posigrade (i.e., in the same direction as the orbital motion) rotation of Venus the morning side of the planet is rotated, in the case of eastern elongations, toward the Earth, and in the case of western elongations - the evening side. Taking into account the thermal inertia of the planet's surface, it may be expected that with eastern elongations the dark portion of the disc has cooled off and the illuminated side has not completely heated up. On the other hand, with western elongations, the dark portion of the planet has not been able to cool yet, and the illuminated side has been heated. Consequently, the brightness temperature averaged over the visible disc of the planet, for identical areas of the illuminated portion of the disc, is found to be lower for eastern elongations than it is for western elongations. As a result of this, there must be a displacement of the moment at which the brightness temperature normally occurs toward the eastern elongations, i.e., before the inferior conjunction. In the case of the opposite direction of rotation, the brightness temperature minimum must be expected after the inferior conjunction.

The experimental data obtained show that there is a displacement of the brightness temperature minimum toward the western elongations, which also corroborates the retrograde direction of rotation.

Measurements of the radio emission of Venus at the 3 cm wavelength performed in 1966 showed that the brightness temperature equals approximately 570 K or +300°C! Scientists did not expect this temperature and therefore they decided to check the results of the experiment. Again and again, at different observatories in the Soviet Union and in the United States measurements were performed of the brightness of the radio temperatures of Venus at different phases and at different wavelengths. The results obtained were very unexpected: at the shortest millimeter wavelengths (from 3 to 10 millimeters) the brightness temperature sharply increases from 300 K or +30°C to 410 K to +140°C (scatter of $\pm 60^\circ$); at centimeter wavelengths the temperature of Venus increases from 420 K or +150°C (for 1 centimeter wavelengths) to 570 K or +300°C (for 4 centimeter wavelengths). Then it decreases somewhat to 540 K or +270°C (for 10 centimeter wavelength), changing with phase by 40 - 70° to each side. At the longer decimeter wavelengths the temperature slowly drops approximately to 520 K or +250°C.

It was impossible to explain this range of temperatures by random observational errors, since the temperature was determined independently by tens of researchers at different locations and with different radio telescopes. It must also be noted that in each experiment there were hundreds of individual measurements and the results obtained were very similar.

However, the surface of Venus must have a certain temperature, /16 which does depend on the instrument used for the measurements, or the measurement location, nor on the wavelength at which the experiment was conducted. These statements are valid only if we measure the thermal radio emissions, i.e., the emission of a heated body emitting infrared rays and radiowaves. However, it may not be thermal radio emission, but emission connected with electromagnetic processes - for example, atmospheric noise arising during thunder

storms and others. What is the cause for this temperature scatter on Venus, and what process can explain such large values?

To understand these phenomena, three hypotheses were examined at the same time. The greenhouse hypothesis of K. Sagan is the mostly widely held hypothesis. Sagan assumes that the surface of Venus actually has a temperature of 570 - 620 K (+ 300 - +350°C) and from its incandescent surface centimeter radio waves leave for the Earth, not undergoing absorption either in the atmosphere or in the cloud layer of the planet. Millimeter waves are absorbed by water vapors contained in the atmosphere of Venus, and they are not emitted by the surface of the planet, but by a certain cloud layer which is relatively transparent, in its atmosphere.

However, what processes produced and maintained the high temperature of the planet?

The greenhouse hypothesis gives the following explanation. Venus represents a gigantic greenhouse. The visible portion of the spectrum of solar rays, making the basic energy contribution, overcomes the cloud layer of the planet. It loses by reflection about 76% of its energy and, undergoing repeated scatterings by cloud particles and molecules of atmospheric gasses, on the way to the planet's surface, it heats the atmosphere and the surface of Venus. The heated surface of the planet must give off its heat, otherwise the surface temperature will increase infinitely. The surface, heated up to several hundreds of degrees, gives off heat into space primarily in the form of infrared radiation. However, on its path in the atmosphere this radiation encounters carbon monoxide and water vapors, which absorb a large portion of the radiation and also heat the atmospheric layer under the clouds and the surface. This heating process continues until thermodynamic equilibrium occurs.

Under these conditions, the greenhouse model of the atmosphere of Venus, consisting basically of carbon dioxide, has the following form. On the surface of the planet the temperature is 570-620 K (+ 300 - + 350 C), the pressure is 2-5 kG/cm². As the distance from the surface increases, the temperature decreases according to an adiabatic law, and it equals 230 - 270 K (- 40 - 0°C) at the cloud boundary at an altitude of about 36 km, at a pressure of 0.4 - 0.1 kG/cm².

The clouds basically consist of water vapors and ice crystals, and possibly of carbon dioxide crystals.

Up to the height of the eclipse level (the beginning of the nontransparent layer of the atmosphere of Venus, which is located at an altitude of 110 k, according to Sagan) the temperature gradient equals 0°C. The pressure at this altitude changes its value $2 \cdot 10^{-8}$ kG/cm². The eclipse level is characterized by the fact that here there is a thin layer of clouds primarily consisting of /17 (C₃O₂) and absorbing the ultraviolet components of solar radiation.

There is one important contradiction to the greenhouse hypothesis: to explain the thermodynamic equilibrium which occurs at a temperature of 570-620 K (+ 300 - +350°C), and a pressure of 2-5 kG/cm², for an atmosphere containing carbon dioxide it is necessary to have in the atmosphere of Venus up to 3% water vapor out of the total composition of the atmosphere. And there is no such amount of water vapor in the atmosphere of Venus.

Another hypothesis - the eolosphere - was advanced by E. Epic. According to this hypothesis, the surface of Venus is heated up to 570-620K (+300 - +350°C), but the cause of this is not solar radiation, but wind, a very strong wind, which raises a cloud of dust and heats the planet's surface due to friction of the dust and gas particles. The zone of strong winds on Venus, which Epic

has called the eolosphere, using the name of the god of wind, Eola - extends from the surface of the planet up to the cloud layer. Solar radiation is absorbed by the dust and generally does not reach the surface. According to this model, Venus is always dark, hot, dusty and windy. Epic confirmed his hypothesis by mathematical calculations, on the basis of which it was established that 2% of the solar energy falling on Venus is sufficient to supply the necessary energy for the winds on Venus. The energy source which maintains the hurricane winds is the zone of the cloud layer and the troposphere lying above it. Here the solar energy is absorbed and powerful atmospheric circulation occurs, producing the winds of the eolosphere layer filled with finely dispersed (brightly colored) dust - for example, carbonate of calcium, magnesium, or silicates.

The atmospheric model of Epic is as follows: the chemical composition of the atmosphere is a mixture of nitrogen and carbon monoxide; the temperature on the surface, as was already noted, is 570-620K (+300-+350°C); the pressure - 4 kG/cm². The temperature gradient (in terms of altitude) equals approximately 10 deg/m, and at the boundary of the upper layer of dense clouds ($H \approx 22$ km) the temperature equals 350-400 K (+80-+130°C), and the pressure - ≈ 0.6 kG/cm². Above, at an altitude of $H = 35$ km, there is a thin cloud layer which is transparent to ultraviolet rays, where the temperature is 234 K (-36°C), and the pressure is 0.08 kG/cm². Above this layer, the temperature gradient up to the eclipse level equals 0°/m. At this altitude Epic assumes that the pressure must equal $2 \cdot 10^{-6}$ kG/cm². The chemical composition of the atmosphere, the temperature regime, the boundary of the clouds and the composition of the clouds are assumed to be the same as in the greenhouse model. However, the eolosphere hypothesis has not found supporters. There are too many assumptions which are not clear and which have not been explained (what is the nature of the circulation which is the source of the planet's surface heating,

how does this model explain the presence of vertical air currents in the eolosphere with powerful horizontal circulation, which must occur between the day and night sides of the planet, etc.). The observations of Soviet and American radioastronomers who have established the dependence of the brightness temperature of Venus on its phase (i.e., on the time of a Venus day) have refuted the eolosphere model.

Let us examine the third hypothesis - the ionosphere model /18
of the atmosphere which for a long time competed with the greenhouse model. According to this model, proposed by D. Johnson in 1961, the atmosphere of Venus at a great altitude has a powerful electroactive medium - the ionosphere, with a thickness of up to 100 km. This ionosphere is the source of the high temperature emission 600 K (+330°C) in the centimeter and decimeter wavelength ranges. The mechanism responsible for the emission of radiowaves in this case is free-free transitions of electrons in the field of ions. This medium has an interesting property: it is optically thin - transparent - for millimeter waves and optically thick - not transparent for the longer waves. The brightness temperature of 350-400K (+80 - + 130°C) observed at the millimeter waves is caused by the surface of the planet.

It must be added that the pressure on the surface, according to the calculations of Johnson, must be 0.3 - 1 kG/cm². In addition, up to the cloud layer which is at an altitude of $H \approx 17$ km and reflects ultraviolet and infrared (8 - 13 km) radiation, the temperature drops to 220K (-50°C), and the pressure - to 0.04 - 0.1 kG/cm². Above the cloud layer up to the eclipse level (which, according to Johnson, is located at $H \approx 80$ km) there is a transparent region where the temperature gradient equals 0 deg/m. The pressure is $2 \cdot 10^{-6}$ kG/cm² at the boundary of the eclipse level. According to this hypothesis the thickness of the atmosphere of Venus is about 200 km, and it consists only of carbon monoxide,

the products of its dissociation, and also of ions.

The calculations have shown that to provide a temperature of $+330^{\circ}\text{C}$, the ionosphere of Venus must have an electron concentration of 10^9 cm^{-3} , whereas on the Earth in the ionosphere the electron concentration is 10^6 cm^{-3} and the electron concentration must be of the same order of magnitude on Venus.

Many attempts have been made to explain the presence of the high electron concentration of the ionosphere on Venus by:

- solar corpuscular radiation which is a powerful source of ionization;
- the presence in the atmosphere of a large number of molecular ions of molecules losing one electron;
- semitransparent ionosphere with a high electron temperature (5270 K , about $+5000^{\circ}\text{C}$) in the region of the maximum electron concentration and with a colder layer located above;
- a porous (perforated) ionosphere having individual regions with a high electron concentration - ionosphere clouds.

However, all of these attempts using experiments and calculations were unsuccessful, and the ionosphere model of the atmosphere of Venus, just like the colosphere model, has died.

What can explain the differences in the temperature recordings on the surface of Venus, and what is the aggregate state of the surface, from what medium are the radio waves reflected?

In 1964 the Soviet scientist A.D. Kuz'min together with the American scientist Barry Clark observed Venus using a movable radio interferometer, consisting of two 27-meter paraboloids (The Owens Valley Observatory, California). The radius of the solid sphere of Venus was measured: 6057 km (before this, astronomers had mea-

/19

sured only the radius of the cloud layer). Thus they determined the average altitude of the clouds - from 40 to 60 km above the surface of the planet, which facilitated the subsequent calculations of the Venus atmospheric model.

Measurements of the Venus radio emission polarization showed that its source is a solid surface, and not the atmosphere nor clouds, since only a smooth solid surface can produce emission which is partially polarized at the edges of the planet disc.

Consequently, the surface of Venus is incandescent. But is its temperature the same everywhere? Observations showed that the hottest point is where the Sun is at the zenith; here the surface is heated up to $+480^{\circ}\text{C}$. At the opposite point - up to $+360^{\circ}\text{C}$. As would be expected, the coldest points of the planet were its poles, having a temperature of about $+250^{\circ}\text{C}$.

The dielectric constant of Venus was determined by measuring the differential polarization of radio emission. It was found to equal 2.5% - much lower than in terrestrial sand (3.5%), wax (5%), and much lower than in water (80%). It was established as a result of these measurements that the outer layer of Venus is porous, and that there cannot be great accumulations of water or any other liquid there.

The dielectric constant of the surface covering of Venus was determined by the radio wave reflection coefficient. For waves of 10 and 70 cm it was found to equal 3.7 - 5%, and for waves of 3 cm - 1% instead of 10%.

The Soviet radioastronomer G.M. Strelkov, analyzing the data from radioastronomical observations, advanced his own theory, which explains the diversity of temperatures on the surface of Venus and the formation of the greenhouse effect in its atmosphere. According

to this theory, the surface of Venus consists of an external, very porous layer, located on a solid rock base. The thickness of the porous layer is several centimeters. Radio waves 3 cm long are reflected from this layer. The longer waves are reflected from the dense base - the foundation, which is characterized by the dielectric constant both for dense sands and even for certain rocks. When we receive the eigen emission of Venus, part of the emission of the foundation is reflected from the boundary and does not reach us. Therefore, according to polarization observations, the dielectric constant is too low. The "drop" of temperatures in decimeter waves is apparently caused by the fact that the waves reach us from a great depth, i.e. from the foundation, and they are also reflected twice during the passage through the boundary of two media.

To explain the formation of the greenhouse effect, G.M. Strelkov started with (simplified for the discussion) a "gray" - i.e., absorbing all waves identically - atmosphere of Venus, and assumed that this effect was caused by the selective capacity of water vapor to absorb radiation only in a certain wavelength range. If this property of water vapor is taken into account, then the necessary greenhouse effect must be reached, according to this theory, with a carbon dioxide content of 5%, water vapor - 0.07%, and a surface pressure of 10 kG/cm². The layer of precipitated water in this case is about 9 g/cm² which agrees with the determinations of the amount of water vapor above the clouds. /20

These investigations greatly strengthen the position of the greenhouse hypothesis of the atmospheric model of Venus.

Recently, along with the greenhouse model, more attention is being given by scientists to the circulation hypothesis of Richardson-Gudy. This hypothesis assumes the mechanical transfer of heat from the equatorial zone to the poles due to temperature differences

in these regions.

The air rises above the tropics to the poles, descends below, and returns to the tropics near the surface.

Great transparency of the atmosphere is thus assumed in the infrared radiation region.

Calculations have shown that the atmospheric motion connected with this convection may reach 30 m/sec in the upper boundary layers. Thus the horizontal temperature differences will rapidly be eliminated (which is confirmed by results of radio interferometry measurements). In addition, the streams, although moving very slowly, may be adiabatic and produce an adiabatic temperature gradient without an inflow of solar radiation.

It is possible that subsequent experiments may show that extensive circulation of this kind will explain the high temperatures on Venus.

As may be seen, there are no weak points in the hypotheses, and scientists have correctly called, and are calling, Venus the mysterious planet. In spite of the fact that the great technology of planetary astronomy - radio telescopes and radar, using sensitive quantum accelerators and gigantic antennas, optical telescopes with infrared receivers and present day spectral equipment - have been directed toward obtaining new information about the physical characteristics of the planet, the interpretation of the data obtained has not been unequivocal.

Studies of the true physical conditions on Venus, which differ greatly from those on the Earth, are of great scientific interest. These problems may only be solved by means of interplanetary stations going to the planet, flying a close distance to it, or descending directly into the atmosphere and landing on its surface.

THE PATH TO VENUS

Thousands of paths lead to error; only one leads to the truth.

/21

Jean Jacques Rousseau

On 4 October 1957 a Soviet man took the first and most important step on the path toward overcoming Earth's gravity - the first artificial Earth satellite was launched onto a circumterrestrial orbit. The era of space investigations of the universe had begun, predicted by the founder of the jet engine school - the great Russian scientist Konstantin Eduardovich Tsiolkovski.

Scientists had in their hands a new instrument which they could use to perform direct studies in space.

The idea of creating a multi-stage rocket-carrier which could place on space trajectories equipment for investigating space, the Moon, and the planets, also belongs to Tsiolkovskiy. This idea was embodied in the metal construction collective, headed by Tsiolkovskiy and his followers, academician S.P. Korolev, in cooperation with many other institutes, organizations, and factories.

The development of the rocket-carrier was a long process - from the drawing board of the designer to the factory for final assembly at the proving ground.

The 3-stage rocket (it may be seen at the Exposition of Achievements of the National Economy in Moscow) had a total length of 38 meters, and the diameter of the base (with respect to the stabilizers) equals 10.3 meters. The first and second stages of the rocket consisted of a central and far hanging side rocket units.

The length of the central unit was 28 meters; the maximum diameter was 2.95 meters. Each of the four side units had a length of 19 meters with a diameter of 3 meters.

The length of the third stage together with the forward unit and the nose cone was 10 meters and the diameter was 2.58 meters.

The power supply of the rocket consisted of 6 liquid rocket engine units (there were 4 engines in each unit) which produced a maximum thrust of 600 tons-force and a total useful power during the flight of 20 million horsepower. The third stage of the rocket provided a velocity which was greater than the second cosmic velocity - 11.2 km per second. Reaching the second cosmic velocity opened up the possibility of interplanetary flight using trajectories previously assigned. Beginning in 1959, this made it possible to use automatic stations to perform a systematic study of interplanetary space, Venus, and Mars. To perform spaceflights to /22 Venus and to perform direct measurements, it was necessary to solve numerous complex problems.

In the first place, using the laws of celestial mechanics, it was necessary to develop a flight trajectory and a flight regime for the station so that the station, overcoming the Earth's attraction and moving under the influence of the Sun, could encounter Venus at a given point in space. The mutual position of the Earth and Venus in space continuously changes due to differences in their periods of rotation around the Sun. However, each of the configurations is repeated every 584 days and, as was already indicated above, at the time of the inferior conjunction the distance from the Earth to Venus is the smallest, and in the superior conjunction the distance between the Earth and Venus is the greatest. This has a great influence upon the selection of the flight trajectory.

In the second place, the flight trajectory selected must correspond to the smallest possible velocity of motion of the station at the end of the powered phase of the flight - with the existing powers of the rocket-carrier engines, this makes it possible to direct the space flight of a station with the greatest useful load.

In the third place, the flight time must be the smallest possible, since as the flight duration increases the danger increases of the station colliding with micrometeors, as well as the probability of a failure in the equipment under the influence of factors in space.

In the fourth place, the initial parameters of the interplanetary trajectory must be strictly maintained, since errors in the velocity of several meters per second or in the orientation of the station by several degrees could make it impossible to encounter Venus.

In the fifth place, to provide reliable radio communications during the encounter of the station with Venus, it is desirable that Venus be as close as possible to the Earth.

In the sixth place, the trajectory selected must provide the smallest possible arrival velocity in the atmosphere of Venus, since thus the overloads and the heating acting upon the descent capsule are reduced, making it possible to reduce the mass of the descent capsule and its thermal insulation.

Since it is impossible to select a trajectory which satisfies all of these requirements at the same time, the problem consists of selecting the most favorable interplanetary trajectories.

Let us try to select a trajectory which corresponds to a flight to Venus along the shortest path.

Such a flight may be devised, if the station "falls" toward the Sun in a straight line, i.e., when Venus is at the inferior conjunction at the time of the encounter.

With such a trajectory, the flight will last about 25 days, and the path traversed will be a little bit more than 42 million kilometers.

In order that the station "fall" toward the Sun, its orbital velocity with respect to the Sun after the launch must be equal to zero. For this purpose, the station must have a velocity of 29.76 km per second (heliocentric velocity of the Earth) and it must move in a direction opposite to the motion of the Earth in its orbit around the Sun. In addition, it is necessary to overcome the Earth's 123 attraction. As calculations have shown, the velocity of the station must be 31.8 km per second in order to "fall" toward the Sun. At the present stage of technological development, these velocities cannot be produced; thus, leaving the solar system is simpler than "falling" towards the Sun.

There is still one great drawback connected with a flight to Venus along the shortest trajectory - at the moment the station encounters the planet the radio emission of the Sun will "clog" the signals from the station, since Venus will be in the inferior conjunction and it will be very difficult to transmit data from the station.

Let us now examine the second flight trajectory which is suitable in terms of energy.

(Caption page 23): Diagram of mutual position of Venus and the Earth during a direct flight to Venus.

(Lower right caption): Diagram of flight to Venus along a Homan-ov orbit (with the least consumption of fuel).

This trajectory is tangent both to the initial and to the final circular orbits (of the Earth and Venus), and the smallest consumption of fuel is required for it. However, there are several disadvantages of a flight along this trajectory.

In the first place, it is difficult to launch the station onto the flight trajectory. At the boundary of the sphere of influence of the Earth, where the perturbing acceleration from the Sun is equalized by the acceleration of the Earth (this sphere has a radius of 900,000 km, and its center is the Earth), the velocity of the station must be 2.5 km per second and must be directed opposite to the direction of the Earth. Small errors in the direction or ^{/24} the magnitude of acceleration during launch for a long flight (about 6 months) may lead to a great miss at the end, since the station describes half of an ellipse moving along its orbit.

In addition, the distance between the Earth and Venus at the moment the station encounters Venus will be about 90 million km.

Thus, correcting the path toward Venus with the smallest fuel consumption may complicate the launch of the station onto the flight trajectory and may extend the flight time and distance between the Earth and Venus at the moment of encounter.

Let us now examine one of the intermediate variations of a trajectory which is optimum for a given weight of the station, the energy possibilities of the rocket, and the flight duration. Trajectories which are presently used for the flights of automatic interplanetary stations toward Venus correspond to this variation.

(Caption page 24): Optimum flight trajectory of an automatic interplanetary station toward Venus.

With such trajectories, the flight time of the station extends from 3 to 4 months and the distance at the time of encounter between the Earth and Venus is approximately 70 million kilometers. Thus, the Sun does not disturb radio communication.

It is true that there is one disadvantage - this is the precise launch date which is rigidly dictated by astronomical times.

The launch may be made when the Earth leads Venus in angular motion around the Sun by approximately 45° .

FIRST LAUNCHES

The first launch onto an interplanetary trajectory toward Venus was made on 12 February 1961, when the Soviet automatic station Venera-1, with a mass of 643.5 kilograms, was launched in the direction of the planet with a heavy Earth satellite onboard.

The basic problems of launching this station were: correcting the methods of launching the spacecraft onto an interplanetary trajectory, establishing the extra-long radio communication links and controlling the station, defining the scale of the solar system more precisely and performing several physical studies.

Communication with Venera-1 was maintained until 27 February 1961, when the distance from the Earth was 23 million kilometers. /25
However, this was a record for long range space communication.

The American scientists were also engaged with the problems of investigating Venus, along with Soviet scientists. The first attempt by American scientists to reach Venus in July, 1962 with

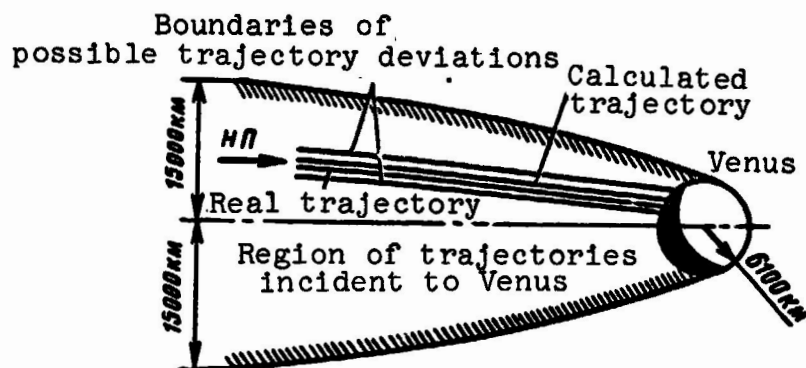


Diagram showing the approach of Venera-3 to the planet Venus

the spacecraft Mariner-1 was unsuccessful. Immediately after the launch, due to trouble in the rocket control system, the rocket deviated from its planned course and was damaged.

In August 1962 the American spacecraft Mariner-2 was launched toward Venus.

The flight of Mariner-2 was successful. On 14 December 1962 the spacecraft passed near Venus at a distance of about 35 thousand kilometers and transmitted the first scientific results - data pertaining to the physical properties of Venus. The results of trajectory measurements of the station motion in the field of attraction of Venus were used to refine the mass of the planet (0.81485 of the Earth). It was established that the magnetic field of Venus is very weak and does not exceed 5 gammas at a distance of 35 thousand kilometers, which is 20-40 times less than the strength of the magnetic field of the Earth at the same distance. The cosmic ray counter did not detect at this distance an increase in the number of charged particles, which points to the absence of radiation belts on Venus. In addition, the radiometer was used to perform measurements of the radio temperature at different points of the planet's disc. These measurements concerned

the hypothesis of a hot surface of the planet. The information, although it was new, did not answer the basic questions in which scientists were interested.

Then November 1965 arrived. Two stations - Venera-2 and Venera-3 - departed at the same time.

The station Venera-2 was launched 12 November 1965, and the station Venera-3 - 16 November 1965.

Each of the stations consisted of two hermetic compartments - an orbital compartment and a special compartment. The special compartment of Venera-3 was the descent capsule in the form of a sphere with a diameter of 900 millimeters.

A pennant was placed in these descent capsules - a metallic globe of the Earth. Within the globe was a metal with the emblem of our country.

Special onboard and Earth-based complexes of radio measuring equipment and computers were used to measure the parameters of the station's flight trajectory and to predict their motion. As a result of trajectory measurements performed after the launch of Venera-2 onto an interplanetary orbit, it was established that the station flight trajectory was close to the calculated trajectory, and therefore it was not necessary to perform a correction. On 27 February the automatic station Venera-2 passed at a distance of 24 thousand kilometers from the planet's surface. /26

The flight trajectory of Venera-3 was corrected on 26 December, when the station was at a distance of about 13 million kilometers from Earth. As a result of this maneuver, on 1 March 1966 the Venera-3 reached Venus and placed a pennant on its surface. Thus the first interplanetary flight was completed, and the possi-

(Caption page 26): Flight trajectory of Soviet automatic interplanetary stations to Venus: 1- launch of Venera-2 , 12 February 1965; 2- launch of Venera-3, 16 February 1965; 3- arrival of Venera-3, 1 March 1966; 4- launch of Venera-4, 12 June 1967; 5- arrival of Venera-4, 18 October 1967; 6- launch of Venera-5, 5 January 1969; 7- launch of Venera-6, 12 January 1969; 8- arrival of Venera-5, 16 May 1969; 9- arrival of Venera-6, 17 May, 1969.

bility was illustrated of reaching planets in the solar system.

During the flight there were 63 communication sessions with Venera-3, and 26 communication sessions with Venera-2.

The experiments performed by the automatic stations Venera-2 and Venera-3 made it possible to solve several important problems of interplanetary flights and to obtain data about space and circumplanetary space during the year of a quiet Sun. The diverse material from the trajectory measurements was of great value for studying the problems of long-range communication and interplanetary flights.

During the flight of Venera-2 and Venera-3, the physical conditions in interplanetary space were studied: the magnetic fields, cosmic rays, streams of low-energy charged particles, streams of solar plasma and their energy spectra, cosmic radio emission and micrometeors.

The flights of Venera-2 and Venera-3 showed that the operating conditions of stations in the immediate vicinity of the planet Venus have not been studied sufficiently - as the planet was approached, there was a temperature increase which exceeded the calculated values, and radio communication with the stations was disturbed. These phenomena were also observed on Mariner-2.

VENUS REVEALS ITS SECRETS

That which we know is limited, and that which we do not know is infinite.

P. Laplace

Truth does not lie on the surface.

Antoine de Saint Exupery

After the launching of the stations Venera-2 and Venera-3, /27 one and a half years passed. A new, favorable astronomical period for launching a station was approaching.

During these one and a half years, on the basis of data obtained from the stations Venera-2 and Venera-3, scientists and designers developed a new experiment, and improved the components, equipment and systems. In many factories, the ideas and calculations of engineers and scientists were embodied in real constructions.

In laboratories and on test stands, the equipment, components and systems developed were subjected to repeated tests and checks. They were "tested" with heat and cold, pressure and vacuum, and subjected to the action of solar rays and to overloads on centrifuges so that they became several hundred times heavier.

Only the designers of the new station were to know how many sleepless nights there are during creative designs.

VENERA-4 - FIRST IN THE ATMOSPHERE OF THE PLANET

It was launched in the daytime on 12 June 1967. At 5 hours 39 minutes the automatic interplanetary space station Venera-4 departed for deep space.

The space flight lasted for more than 4 months. During this time the station was in communication with the Earth one hundred and 14 times and transmitted a great amount of information about the processes occurring in space and about the operation of the onboard systems.

On 18 October 1967 at 7 hours 34 minutes Moscow time the station Venera-4, after having traversed about 350 million km, entered the upper rarefied layers of the planet's atmosphere. The descent capsule was separated from the station, which outlined the horizon of Venus with a fiery arrow, was braked in the atmosphere of the planet, and completed its descent by parachute in about one and a half hours. During this time it transmitted scientific information about pressure, temperature, density, and chemical composition of gases in the atmosphere of Venus.

The first scientific investigations were carried in the atmosphere of the secretive planet.

What were the results of this unusual space experiment?

/28

The measurements performed on the Earth-Venus trajectory confirmed many data obtained in previous interplanetary flights. In addition, these measurements showed that in 1967 the intensity of flares of solar cosmic rays, characterizing solar activity, increased by a factor of 100 as compared with 1964-1965.

Observations on the section of the trajectory before the planet was reached established that the flux of cosmic particles of high energies (up to distances of 5000 km from the surface of Venus) was constant and equaled the flux far from the planet. Below the magnitude of the flux decreased due to its absorption by the planet. This result indicated that there are no radiation belts on Venus, similar to those of the Earth.

Measurements of the magnetic field show that Venus does not have a magnetic field, whose dipole moment would have to be more than 3 ten-thousandths of the dipole magnetic moment of the Earth.

This result refuted the opinions held up until then that all the planets in the solar system had magnetic fields similar to that of the Earth.

The measurements of the fluxes of solar plasma close to the planet showed that at distances from 19 to 12-13 thousand km from the surface of the planet there was a great increase in the fluxes of solar plasma. This may be explained by the station passing through the front of a shock wave, formed during passage around the planet (like a solid body) by a supersonic solar wind with a magnetic field "frozen" in it

The concentration of charged particles in the region of the upper atmosphere of Venus (an altitude above 100 km) does not exceed 1000 particles per cubic cm, i.e., two orders of magnitude less than the maximum concentration of charged particles in the ionosphere of the Earth. These data shed light on the question of the ionosphere of Venus and gave the impression that the concentration of charged particles in the ionosphere is several orders of magnitude greater than the concentration in the ionosphere of the Earth.

It was established that at a distance of about 10,000 km from the surface of the planet there is neutral hydrogen in its atmosphere, which forms a hydrogen corona of Venus, which contains a thousand times less hydrogen than the upper atmosphere of the Earth. No atomic oxygen was detected up to an altitude of 200 km.

Finally, that which scientists awaited with great impatience throughout the entire world. It is known how contradictory were

the data about the temperature, pressure, and density, and composition of gases in the atmosphere of Venus. Now scientists had in their hands data on the physical characteristics of the atmosphere of the planet, obtained directly from its depths.

It was established that:

— The basic component of the atmosphere of Venus is carbon dioxide - $90 \pm 10\%$. Oxygen - more than 0.4%, no less than 1.5%; water - no more than 1.6%; nitrogen - less than 7%;

— At an altitude of 55 km the atmospheric temperature was $+25^{\circ}\text{C}$ and it increased to $+270^{\circ}\text{C}$ when the descent capsule descended to a height of 27 km. (end of communication);

— Atmospheric pressure and density, when the descent capsule /29 descended from an altitude of 55 km to 36 km (measurement limit of equipment) changed from 1 to 18.5 kg and $1.2 \cdot 10^{-3}$ to $[16.5 - 18.3] \cdot 10^{-3}$ grams per cm^3 , which on the average in order of magnitude, exceeded the maximum density of the terrestrial atmosphere.

It was initially assumed that the measurements were performed down to the planets surface.

It is interesting to note that at such high pressures and densities of the atmosphere of Venus water must boil at a temperature above 200°C .

As we can see, conditions on Venus are far from a paradise, /30 and are entirely unsuitable for humans.

A day after the station Venera-4 descended into the atmosphere of Venus, the American spacecraft Mariner-5 passed close to the planet. This spacecraft at a distance of more than 4000 km performed

(Captions page 29): [Upper left]- Data from measurements performed by the automatic interplanetary station Venera-4 in the atmosphere of the planet.

[Lower right)- Automatic station Venera-5.

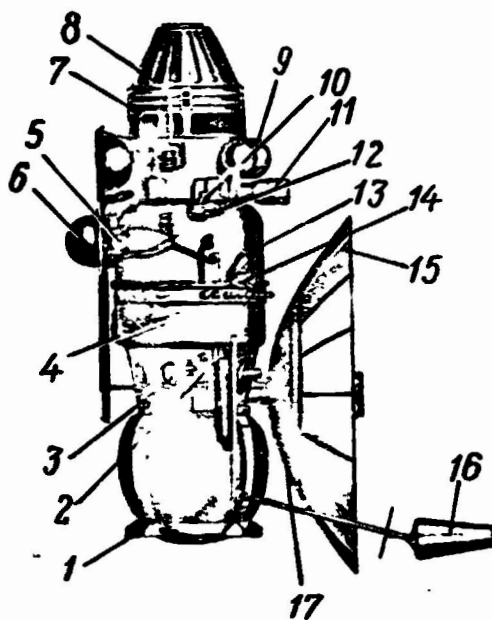
radio observations of the upper layers of the atmosphere. The data obtained could be interpreted only after processing the results of investigating the composition of the planet's atmosphere, performed by the station Venera-4, and also by using data obtained from radar observations of Venus.

The scientific data obtained by Venera-4 were able to qualify and explain many phenomena occurring on this planet.

However many problems still remain unsolved, and many data were unknown. What are the pressure, density, temperature, and composition of the atmosphere on the surface of the planet? What is the composition of the cloud layer and the rocks covering the surface? What are the processes occurring on Venus which are responsible for the high values of the atmospheric parameters of the planet and its unusual composition? What are the velocities of air streams in the atmosphere? Is it dark or light on the surface of Venus?

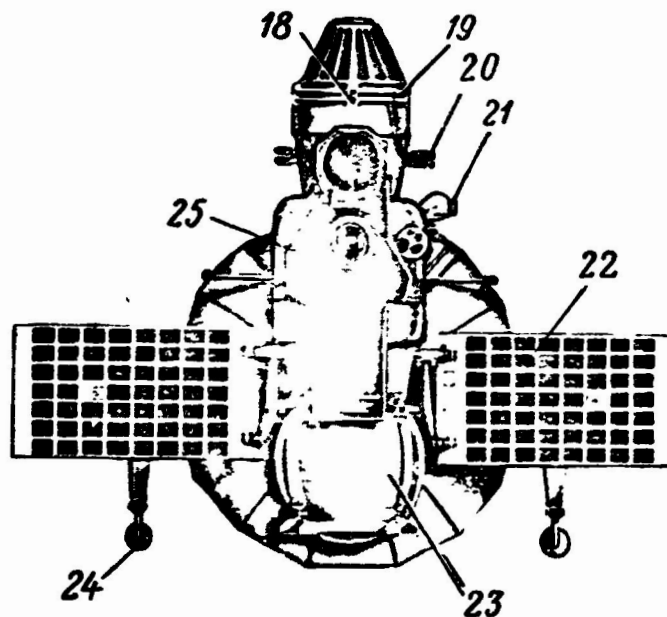
There are many answers to the last question (and also the remaining ones).

Some scientists assert that, due to the thick cloud cover and the large pressure, light cannot reach the surface of Venus. Others maintain the opposite - solar light, scattered in the clouds, produces uniform illumination of the sky with no shadows, as exists on the Earth on a gray, cloudy day. A third group maintains that the great density of the atmosphere distorts the passage of the light rays so much (phenomenon of super-refraction) that an observer



Layout of the automatic interplanetary station Venera-5:

1- Ring for attaching station to reactor unit; 2- Unit for automatic control of microengines of attitude control systems; 3- High pressure tanks of attitude control system; 4- Orbital compartment dryers; 5,6,10, 12- Sensors of astro attitude control systems; 7- Collectors of gas attitude control systems; 8- Correcting engine mounting (CEM); 9- CEM tanks; 11- Blind of attitude control sensor; 13- Orbital compartment; 14- Ultra-violet photometer; 15- Narrow directional parabolic antenna; 16,24- Narrow-directional antennas; 17- Radiator of thermal control system; 18,19,20- Microengines of attitude control system; 21- Cosmic particle counter; 22- Solar battery panel; 23- Descent capsule; 25- Light protecting screen of astro attitude control system sensors.



on Venus cannot see the edge of the horizon but sees, figuratively speaking, the back of his own head.

VENERA-5 — VENERA-6 — 20 KILOMETERS TO THE SURFACE!

After having analyzed the data, which were already history, obtained from the station Venera-4 and after having noted the new problems, the scientists and designers got ready for the next astronomical period (beginning of January, 1969) to launch new spacecraft towards Venus.

It was again a busy period for designers, workers, and researchers. The necessary changes were introduced into the construction of the new station based on the flight data from Venera-4. Again there were rigid critical tests of each component, each system, each part against the cold, heat, vacuum, pressure, solar radiation, vibrations, and overloads.

However, all of this was already behind. We had before us the interplanetary automatic stations of the 1968 series, created by the genius of the Soviet people - the sister-twins Venera-5 and Venera-6, which were going to make a voyage into deep interplanetary space.

The factory tests were completed. Now the stations and the rocket-carriers, lovingly called the "little horses" by the designers, stood on the cosmodrome.

There, in the covered hangar, after several tests and checks, the station and the rocket-carrier first meet, to be combined, placed on the launch pad, and, by means of the fiery team of jet engines, rise into space and there are forever separated.

/33

(Caption page 32): Pennants of the station Venera-5.

(Caption page 33): Automatic station Venera-6.

Though we may not be surprised to read in the papers about the launch of the satellites in the cosmos series, the satellites of deep space communication Molniya-1, the meteorological satellites of the meteor system, the multi-ton scientific laboratories Proton, and the automatic stations following the Moon and Venus, we must not forget that each launching of a rocket with space equipment on-board represents the labors of thousands of specialists. Each launch is a joyful and uneasy holiday for everyone who took part in creating a new spacecraft. This is the day of its birth.

The launching of the stations Venera-5 and Venera-6 is approaching.

The launch of two automatic stations at the same time has the purpose of simultaneously measuring the parameters of the atmosphere of Venus at 2 different regions of the planet. This has imparted a new accent to the space experiment on investigating the atmosphere of Venus.

Astronomical times strictly determine the month, day, hour, minute, and second when the Earth is in the most favorable position for the launch.

The launch takes place on 5 January 1969, at 9 hours, 38 minutes. The last seconds before the launch are passing. Everyone gives concentrated attention to the command post, the observation points at the Center for Deep Space Communication at the Coordinating 34 Computer Center. Briefly, in a businesslike way, the last words of command resound in the loudspeakers and headphones: "Switch to vent", "start", "ignite", "open ShR*", "rise."

* Translator's note: expansion unknown.

The tower-like scaffolding collapses on the Earth. The base of the rocket is hidden in clouds of dust and flame, the body of the rocket shudders, rises from the launchpad, first slowly and then more rapidly rising upward, carrying with it columns of flame and a tail of smoke and the howling noise of the jet engines.

Several tens of seconds have passed, the clouds of dust and smoke on the launchpad have still not disappeared and only a flashing point, a light ray coming from the celestial heights speaks of the event which just occurred. And in the loudspeakers a quiet voice: "Thirty seconds, flight normal", "One hundred seconds, flight normal", "The first stage has separated - flight normal", "The last stage with the automatic station has gone into the orbit of an Earth satellite - flight normal", "Orbital parameters ...".

On the lighted map in the Coordinating Computer Center a line traces a projection of the rocket flight.

When the light point moves over the Atlantic Ocean in the region of the gulf of New Guinea, the voice of the operator is heard: "Position of the rocket normal", "Time of the second launch", "Separation charges in operation", "Ignition", "Launch", "Engine of last stage operated the calculated time", "Separation completed", "Center of Deep Space Communication is receiving telemetry information", "Antennas and panels of the solar batteries have opened", "Pressure and temperature in the compartments and current in the solar batteries are normal", "Communication with the station is stable", "The station has entered a flight trajectory to Venus close to the calculated trajectory!!!".

The station Venera-6 passed smoothly through five days of flight.

About 4 months ahead of the station along the thorny paths of space lay its goal - Venus.

Now the stations are in the hands of the radio operators and the control specialists. Using the automatic radio equipment, the control devices onboard the station and on the Earth, they will carry out "radio communication" with the stations. They will know how to operate the equipment and systems of the stations, what the temperature regime is and what the pressure is in their compartments. Along with the ballistic experts, they will perform trajectory measurements and will determine the route which the stations are travelling.

The electronic computers of the Coordinating Computer Center will convert the radio signals from the stations into columns of figures and graphs which are understandable to the specialists.

The values of different parameters characterizing the operation of the equipment and systems on the stations, and also the flight time from the launch date, will be shown on the single panel of the Coordinating Computer Center in a generally understandable form.

The stations will complete the four-month flight to Venus using their instructions.

As we may recall, the stations set out on the flight wrapped /35 in their snow white covering - the thermal insulation. The purpose of this insulation, together with the thermal control system, was to maintain a temperature regime given by the flight program in the hermetic compartments and in the station housing.

Let us take off the "fur coat" from the station Venera-5, let us transmit commands to the mechanisms controlling the opening

of the panels of solar batteries and antennas, and let us become familiar with this equipment. It is similar and not similar to its predecessors - Venera-2, Venera-3 and Venera-4. It took over from them everything which passed the tests in space, discarding those elements of construction and of the systems whose reliability was not confirmed during the flight of its predecessors.

The basic power element of the station construction is the cylindrical orbital compartment which includes, on one side, the correcting engine and, on the other side, on a special frame - the descent equipment - a scientific laboratory for studying the atmosphere of Venus. Panels of solar batteries are attached to the orbital compartment, which, constantly oriented towards the Sun during the flight, will transform the light energy into electric energy and will recharge the buffer batteries - the chemical sources of electric energy - of the orbital compartment of the descent capsule. The panels of the solar batteries contain two conical spiral antennas of the onboard radio equipment.

The following are mounted on the orbital compartment: parabolic (narrow directional) antenna of the radio equipment, whose base plays the role of a radiator-heat exchanger of the heat control system, optical centers of the astroorientation system; additional components of the astro orientation system - micro-engines operating on compressed gas; tanks with compressed gas; sensors of the scientific devices which perform scientific investigations on the flight trajectory and in circumplanetary space.

To decrease the overall dimensions, before the launch the panels of the solar battery and the antenna are combined, and when the engines of the last stage of the rocket-carrier are turned up, the stations separate and all of the structural elements assume their working position.

The orbital compartment represents a hermetic container designed to operate under space conditions. The container contains apparatus, equipment, and systems of the station which are necessary for the Earth-Venus trajectory. These include: onboard radio equipment, systems of heat control and regulation; components of the attitude control systems; scientific equipment; energy supply system; chemical sources of current.

As was already noted, during the development of all these devices and systems, particular attention was given to providing great reliability in the operation of the entire complex. In addition to rigorous tests to which all equipment and systems of the station were subjected, redundancy was widely used in the equipment, devices, and systems. This redundancy meant duplication, and in some cases, at particularly crucial points, there was triple redundancy of equipment, units and partial and complete systems.

Each of these systems on the station fulfills certain, rigorously defined functions assigned to it by the flight program. /36

Let us examine the operation of one of the basic systems of the station - the radio equipment in the orbital compartment.

The radio equipment consists of two sections - receiving and transmitting, which operate in several regimes and do the following: control the equipment, apparatus and systems of the station (command radio link); telemetry measurements (direct transmission of the values of the parameters characterizing the operation of all systems on the station during the communication sessions); recording in the memory device, reproducing, and transmitting to the Earth scientific information and data regarding the operation of the attitude control system compiled between communication sessions; performing trajectory measurements concurrently with Earth-based radio equipment - determining the location of the station in terms of

angular coordinates, velocity, and distance.

One of the three antennas carried on the station receives the control command-signals, transmits information from the station to the Earth, and performs trajectory measurements on the Earth-Venus flight. This is a narrow directional parabolic antenna with a diameter of 2330 millimeters, or one of the two unidirectional antennas depending on the communication task and the distance of the station from the Earth.

The radio equipment for solving the problems formulated consists of two groups of receivers, two groups of transmitters, decoders, automation equipment and equipment for producing signals, modulating devices supplying the generators, telemetry commutators, and several other units and devices. The operation of this complex radio equipment is controlled either automatically from the onboard programming equipment, or by radio commands from the Earth.

Each radio communication session has its own specific task and must be rigorously fulfilled in agreement with the established program, since all the commands are logically connected with each other and not fulfilling one command may hold up the communication session or completely cancel it.

The following communication sessions are held depending on the purpose:

- Earth-based, in which the operation of all the onboard systems are carefully checked and trajectory measurements are performed;

- The standard session of telemetry measurements and transmission of scientific information on the flight trajectory;

— A standard session of trajectory measurements on the flight trajectory, in which the distance, velocity of the station, and its position in space are determined;

— Flight trajectory correction session;

— Communication session as the planet is approached before entry into the atmosphere of Venus.

When discussing the radio equipment of the station, we should point out the difficulty in operating it from the great distances of space. On Earth, we are accustomed to the fact that radio waves sent from a radio station reach the receivers simultaneously. The situation is entirely different with communication at interplanetary distances - there may be several minutes from the time a command /38 is given until it is received. In the concluding stage of the flight, from the issuance of a command until receiving an answer, onboard the station there is time to quietly do one's morning exercises or prepare a cup of tea and pastry. The commands from Earth are transmitted in accordance with those time intervals which are determined by the flight program.

Between the communication sessions, the radio equipment of the station remains ready to operate, i.e., only one receiver and the corresponding electronic equipment providing the command radio link of the station are turned on. When a command is received from Earth, the control devices switch on the units of the radio equipment, system, and components of the station which must be put into operation based on this command.

In accordance with the assigned program, the receiving-transmitting equipment and the radio equipment units are turned on automatically or on command from the Earth.

(Caption page 37): Flight diagram of Venera-5 with the communication sessions: 1- Communication session; 2- Communication session on narrow directional antenna; 3- Trajectory correction session; 4- Communication session on narrow-directional antenna; 5- Planetary communication session.

Thus, if any of the equipment or elements break down, there is a reserve device or reserve system always ready to replace it.

It must be noted that during the flight of the stations Venera-5 and Venera-6 these measures did not have to be taken. The equipment operated perfectly.

In speaking about the operation of radio equipment in space, it is necessary to point out other great difficulties which greatly complicate radio communication. First of all, this includes radio interference coming from the Sun, other stars, constellations, and nebula. The radio signals of the station weaken at great distances and become comparable with the interference. As radio operators know, it is necessary that these signals be separated from the interference, filtered, amplified, and changed into clear signals which are recorded on magnetic tape in the memory devices at the Control Center, introduced into computers, and transformed into digital or graphic data.

Another factor complicating radio communication is the great increase in the flight velocity of the station as it approaches the planet, when the most valuable scientific information is being transmitted. Thus, in accordance with the so-called Doppler effect there is a change in the radio wavelength due to a great change in the transmitter velocity with respect to the receiver on the Earth.

These difficult problems have been handled by the engineers and operators in the Center of Deep Space Communication, providing reliable operation of the receiver antenna and other equipment.

(Caption page 39): Antenna of the Center of Deep Space Communications.

When we see these eight 16-meter antenna dishes of the Center of Deep Space Radio Communication collected on one structure, it seems impossible that this machine, with a height of a ten-story building, can accurately trace the flight of the station within several angular minutes, and move on its supports with great flexibility fulfilling the wishes of the operators.

Electric energy must be supplied for the normal operation of the onboard radio equipment and all the remaining systems of the station.

The power system of the station, in addition to the solar batteries - semiconductor transformers which occupy an area of 2.5 square meters - and chemical batteries, there are current transformers, a power supply control block, ampere-hour counters, and a control system.

/40

This equipment enables the systems of the station to operate in a range from tens to several hundreds of watts of required power.

When the station approaches Venus, the light flux from the Sun increases according to the square of the distance, and consequently the amount of electric energy processed by the solar batteries increases. This leads to overcharging of the chemical sources of current, and the flight program calls for the appropriate switching of sections of the panels of solar batteries, making it possible to maintain the current value within given limits.

One of the basic life support systems of the station, on which the successful operation of the remaining systems depends, is the

thermal control system. At the beginning of the flight, it must protect the station from freezing, and when approaching Venus - from the all-encompassing solar rays. The problems are diametrically opposite.

The necessary thermal regime of structural elements and on-board systems is provided by combining the passive and active methods of thermal control.

The passive thermal control system represents thermal insulation and the corresponding cold covering. The thermal insulation does not sharply change the thermal flux either to the minus or the plus side, and the cover of the surface provides the necessary thermal radiation of the heat excesses of the station. It absorbs the thermal flux when the temperature in the structural elements must not descend below a given limit.

The active method is implemented by an air system of thermal control of the hermetic compartments with fans, heat exchanger-radiators, temperature sensors, a control system, pipes and channels.

The most rigid requirements were placed on the operation of this system during stand tests on the Earth.

However, not all of the operational regimes can be checked under terrestrial conditions. For example, it is impossible to reproduce the state of weightlessness for a long period of time, during which the distribution of heat in the station compartments changes, since in this case convection is excluded from the heat exchange entirely. Therefore, the heat control system, in addition to the fan which exchanges the air between the station compartments and the heat exchanger, contains blowing fans at locations with the greatest amount of heat liberation. These fans operate when the heat liberating equipment or system are in operation.

The heat control system operates according to the following cycle. During the flight the basic source of heat in the compartments is the operational equipment of the station. There is a gradual increase in the temperature in the compartments. When the upper limit is reached, a valve is opened on a command from the heat sensor, the air from the compartment enters the heat exchanger (cold circuit) and gives off heat from its walls, which is radiated into space. Then the air is cooled, and again enters the station compartments, where it removes heat from the heated equipment and again returns it to the heat exchanger. This continues until the temperature in the compartments does not go below a minimum level. Then the valve closes, and the entire cycle is again repeated when the heat accumulates. /41

In this regime the heat control system operates for approximately one half of the flight time. Then the radiant energy of the Sun begins to have a great influence upon the heat balance in the station. Therefore, provision is made for a regime of constantly switching on the cold circuit, providing the necessary heat regime in the compartments on the second half of the flight.

This appears to be simple, but this simplicity was only achieved under experience gained from the flights of previous stations, a great number of experiments on the Earth, and the tedious work of designers and engineers.

Thus the thermal control system operated successfully during the flight; nowhere in the compartments did the temperature exceed 20 - 25°C. The most favorable regime for the operation of all equipment and systems was provided.

The position of a ship on the oceans is determined by means of celestial bodies. Making a calculation and determining the deviation of the ship from a given course, a command is given to the

rudder to change course, and in the machine room - a command to change the velocity of the ship in order to arrive in time at its port of destination.

Thus, our messengers, stations Venera-5 and Venera-6, must arrive precisely at their port of destination - the planet Venus - at a definite time, so that the time of their arrival may be determined by the Center of Deep Space Communication, located in the Soviet Union.

The role of the pilot in the navigation of our stations is played by the attitude control system and the correcting engine. How did they handle this problem?

There are 3 basic operational regimes of the attitude control system.

The first regime is the so-called regime of constant solar orientation. In this regime the panels of the solar batteries are always directed toward the Sun and charge the chemical current sources - the batteries. If this regime were not maintained, the station would be out of operation in several days.

This regime is provided by means of an optical-electronic sensor of constant solar orientation. If the Sun is in the center of the field of view of the sensor, then the mismatch signal equals zero and no control commands are given to the actuators (micro-engines). If the Sun passes out of the field of view of the sensors, an unbalance of the electronic circuits occurs, the control system turns on the control microengine, which gives the station the necessary impulse and returns it to the initial position.

In view of the fact that the regime of solar battery panel orientation is extremely important to the operation of all systems

on the station, it has a redundant regime of gyroscopic torquing /42 of the station around an axis perpendicular to the surface of the panels of the solar batteries. First the panels are oriented towards the Sun by means of another solar sensor.

The second regime is a regime of orienting the parabolic antenna toward the Earth. In this regime, when the entire power of the onboard transmitter is used most effectively, since the radio signals are focussed by the antenna in a narrow beam and are directed toward the Earth, it is possible to transmit the greatest amount of information with a maximum signal magnitude. This is particularly important when the station is tens of millions of kilometers from the Earth.

To implement this regime the attitude control system contains two movable "tubes" - one with solar sensors, the other with Earth sensors.

The values of two angles are calculated using the data from trajectory measurements performed by means of the onboard and the Earth-based radio equipment - the angle between the longitudinal axis of the station and the direction to the Sun, and the Sun-station-Earth angle.

The values of these angles are transmitted along the radio link to the memory block of the control system. On a command from the Earth, the solar and Earth "tubes" are placed (turned) at these angles, after which the orientation session with the Earth begins.

Using the microengines of the control system, the solar sensor is turned in the direction of the Sun, and then the longitudinal axis of the station is made to coincide with the direction toward the Sun, after which the station is turned around its axis until the Earth is captured by the Earth sensor. Thus the parabolic

antenna is directed toward the Earth with an accuracy of several angular minutes, and the radio communication session with the Earth begins.

At the end of this session, by means of the same microengines, control system, and solar sensors the station changes into a regime of constant solar orientation.

The third regime is the regime of trajectory correction.

As was already indicated, when the station is launched on a flight trajectory to Venus it is influenced by the thrust of the engines, the pulses from the stabilization engine system, the field of attraction of the Earth, Sun, Moon and planets, and several other factors. The magnitude of the influencing forces is not always known exactly and cannot always be taken into account. As a result of this, the true flight trajectory of the station differs from the calculated trajectory. Apparently it is necessary to determine the magnitude of this divergence and to correct the station's flight trajectory. This divergence was calculated by means of data from trajectory measurements, and a determination was made of the magnitude and direction of the correcting pulses and the values of the angles at which the stations must first be turned in space before the corrections.

The radio link was used to transmit the values of the angles, and the operational time of the correcting engine in the form of entries (digital code) in the electronic units of the station memory.

Then a very important flight regime occurs - the correction regime.

In this regime a high accuracy of attitude control and operation of the correcting engine is necessary.

The reference stars during this session were the Sun and the star Sirius. The station was oriented with respect to the directions to these heavenly bodies. For this purpose, the values of the orientation angles contained in the memory of the station were calculated.

/43

During the correction sessions, both stations were oriented so that during the operation of the correcting engine, it was possible to eliminate the mismatch between the trajectories - the true and the calculated ones - to have the station arrive at the given regions of Venus at the calculated time - about 9 hours Moscow time, 16 May 1969 for Venera-5 and 17 May 1969 for Venera-6, when Venus was in the radio visibility zone of the antennas of the Center of Deep Space Radio Communication.

The entrance into the atmosphere of Venus was selected with allowance for the following considerations. Since the maximum of the antenna pattern of the descent capsule transmitting antenna coincided with its longitudinal axis, during the descent by parachute the antenna pattern would coincide with the local vertical. If, during the descent, the local vertical coincided with the Venus-Earth direction, then the signal received on the Earth would be the strongest. Therefore the most favorable region for the station to enter the atmosphere of Venus lay in the center of the planet disc visible from the Earth.

Under these conditions Venus is always approached from the dark side of the planet, and the entry point into the atmosphere is located on the nonilluminated side of Venus. For the stations Venera-5 and Venera-6, the entry point into the atmosphere of Venus was on the night side of the planet at a distance of 2700 kilometers from the terminator line, i.e. the boundary between day and night.

The spacecraft had to enter the atmosphere of the planet at a definite angle. With such a dense atmosphere as is observed on Venus, the value of the spacecraft entry angle into the atmosphere has a very large value. Too steep an entry leads to a sharp increase in overloads and great heating of the descent capsule during the aerodynamic braking in the atmosphere of the planet, which disturbs it. At small entry angles, i.e., a flat entry, it is possible that the space station may not be "captured" by the atmosphere of the planet, thus braking in the upper layers of the atmosphere is insufficient, and, instead of submersion in the atmosphere there is a rebounding - the station, changing its trajectory, flies past the planet. Therefore, there is a certain admissible range of entry angles into the atmosphere.

For the stations Venera-5 and Venera-6, the entry angles into the planet atmosphere are 63 - 65 degrees with respect to the local horizon, and the entry velocity is 11.18 km per second.

To orient the station, very small moments of forces are required, produced by the microengines. The magnitude of the moments occurring during the operation of the correcting engine exceeds by several orders of magnitude the moments of the microengines. Therefore, after the orientation of the station with respect to the Sun and the star Sirius is completed, and before the correcting engine is turned on, the gyroscopic stabilization system is set into operation, which controls the operation of the stabilization engine and stabilizes the station before the correcting engine ceases to operate. /44

On 14 and 16 March, 1969, when the stations Venera-5 and Venera-6 were located 15.5 and 15.7 million kilometers, respectively, from the Earth, the correcting engines were turned on at exactly the calculated time upon a command from the onboard computers. These engines operating for a set period of time placed the station

on trajectories placing the station in a given region on the planet Venus.

The trajectory measurements performed after the correction session confirmed the validity of ballistic calculations and their high accuracy. The time at which the station entered the atmosphere of Venus was predicted with an accuracy of several seconds, and the coordinates of the entry region - with an accuracy up to 200 kilometers. Since the first correction was performed with great accuracy, the second correction was not required, although the flight program called for it.

A new surge of operations began. The communication sessions near the planet approached and investigations were made during the descent of the descent capsule into the atmosphere of Venus.

It was necessary to once again check the equipment in the orbital compartments and the descent capsules, as well as the entire command - receiving radio equipment on the ground.

What was the descent capsule like:

In form, the descent capsule was similar to a sphere whose diameter is about 1 meter, with a mass of 405 kilograms. The external surface of the sphere, particularly its lower section, had powerful heat insulation maintaining an influx of heat from the sphere surface in the hermetic container as the descent capsule moved in the dense layers of the atmosphere. The descent capsule entered the atmosphere at the second stage velocity - about 11 kilometers per second and behind a shock wave which was in front of the capsule. As a result of the aerodynamic braking, the temperature exceeded 10,000°C. The surface of the descent capsule could not withstand such a temperature, and would simply melt.

(Caption page 45): Descent capsule.

In addition, during the braking enormous overloads arose, as a result of which the force of gravity of each component on the descent would be approximately 450 times greater than on the Earth under normal conditions.

These two factors alone show what extensive difficulties were faced by the designers of the descent capsule.

The descent capsule consists of two compartments insulated from each other: an upper one - the parachute compartment - and the lower one, the equipment compartment.

The parachute compartment contains a two-stage parachute system consisting of a drogue and a main parachute. The material of these parachutes retains the required mechanical strength at temperatures above 500°C.

This compartment also contains a transmitting antenna of the radio equipment, sensors of the scientific equipment, and the radio altimeter antenna. The parachute compartment contained a /46 hermetic cover which could be discarded.

The equipment compartment of the descent capsule contained the onboard radio transmitter, a programming device, automatic processing units, the telemetry system, a radio altimeter, a battery, thermal control system, and scientific equipment.

To increase the stability of motion of the descent capsule in the atmosphere of Venus and to decrease the amplitude of the oscillations, the lower section contained a special mechanical damper.

The descent capsules contained space passports of the space station - pennants with a bas-relief of Vladimir Il'ich Lenin and a picture of the head of the Soviet Union.

It should be noted that the descent capsules of Venera-5 and Venera-6 were subjected to structural changes as compared with the descent capsule of Venera-4. The descent capsule of the station Venera-4 was produced when the range of assumed pressures and temperatures on the surface of Venus fluctuated from one to hundreds of kilogram-force per square centimeter, and from -30 to $+400^{\circ}\text{C}$. Therefore, it was designed for an average model of the atmosphere of Venus, and could sustain a pressure of about 20 kg/cm^2 .

The values of the atmospheric parameters, obtained after preliminary processing from the station Venera-4 at a radio altimeter reading of 28 kilometers and in the deeper layers, closely coincided with the value for the path traversed when the capsule descended into the atmosphere of the planet from the time the altitude reading was obtained until communications ended. The data thus obtained closely coincided with the value of the altitude calculated from conditions of hydrostatic atmospheric equilibrium.

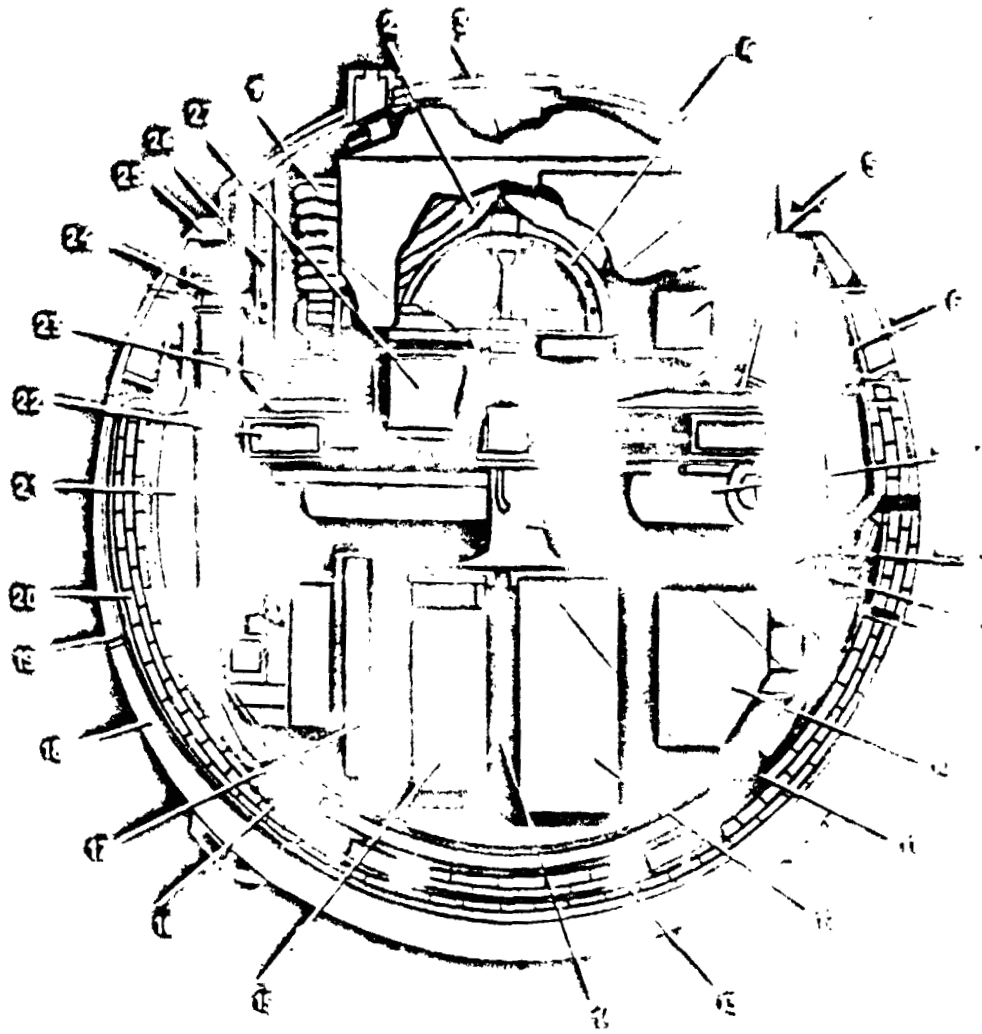
This agreement of the results, obtained by different methods, provided a basis for concluding that the measurement of atmospheric parameters was performed by the descent capsule of the station Venera-4 down to the very surface of the planet.

As a result of further careful processing of the data obtained by probing the atmosphere of Venus by the station Venera-4, along with data from subsequent radioastronomical and radar investigations, and also with the data obtained by Mariner-5, the scientists assumed that the values for pressure and temperature on the surface of the planet were higher than was indicated by the station Venera-4. Thus, one characteristic was taken into account in the operation

of the radio altimeter of Venera-4: two values of the altitude, which differ from each other by 30-40 kilometers, could correspond to the readings of the radio altimeter. This phenomenon is intrinsic to all radio altimeters with a periodic frequency modulation, and an inaccurate knowledge of the atmospheric properties of Venus could lead to the fact that the opening of the parachute and the beginning of measurements were begun much earlier than the calculated values of the altitude at the upper threshold of indeterminacy. Therefore, the measurements performed from the descent capsule of Venera-4 were begun at an altitude of 55 kilometers, and not at 28 kilometers, and ended at an altitude of 27 kilometers above the surface of the planet, when the external atmospheric pressure, after reaching a value which was greater than the limiting value for the strength of the descent capsule housing, crushed /48 the upper cover of the equipment compartment and disrupted the operation of the radio equipment.

During the preparations for the new experiment, it was tempting to reinforce the housing of the descent capsules of Venera-5 and Venera-6, so that they could probe the atmosphere right down to the surface of the planet. However, since strengthening the housing of these capsules by a factor of 5-8 - such as the atmospheric pressure on the surface of Venus would require - would make them very heavy and, as a result, decrease the scientific equipment and also since there was not time for such radical reconstruction of the descent capsule (the astronomical time of launch was very close), it was decided not to introduce serious changes in the construction and composition of the scientific equipment of the descent capsule.

The basic purpose of the scientists in launching the stations Venera-5 and Venera-6 was to increase the accuracy of measuring the chemical composition, the atmospheric parameters and the altitudes corresponding to them, as well as increasing the distance



Layout of descent capsule:

1- Drogue parachute; 2- Main parachute; 3- Cover of pyro-plunger; 4- Transmitting antenna; 5- Densimeter sensor; 6- Grooving charge valve; 7- Dryer; 8- Fan of thermal control system; 9- Hermetic outlet; 10- Commutation unit; 11, 16- Acceleration sensors; 12- Transmitter; 13- Mechanical oscillation damper; 14- Power unit; 15- Onboard transmitter; 17- Programming equipment; 18, 19, 20- Structural elements of external thermal protection; 21- Internal thermal insulation; 22- Thermal control system; 23- Descent capsule housing; 24- Pyro-plunge; 25- Cover of parachute compartment; 26- Radio altimeter antenna; 27- Gas analyzer.

(Caption on page 48): Data from measurements performed by Venera-5 in the atmosphere of the planet.

penetrated into the atmosphere of Venus.

The housings of the descent capsules were strengthened so as to maintain an external pressure up to $25\text{--}27 \text{ kg/cm}^2$ and higher temperatures and overloads as compared with Venera-4.

The area of the main parachute was decreased in order to increase the descent velocity of the descent capsule into the atmosphere of Venus by a factor of 4, since the parachute of Venera-4 was designed for smaller density values of the planet atmosphere.

The scientific equipment on the descent capsules would also change somewhat. A new, more advanced radio altimeter was installed, in which there is no possibility of indeterminate measurements.

ENTRY AND DESCENT INTO THE ATMOSPHERE OF VENUS

It is early on the morning of 16 May 1969. The rosy horizon is covered by haze. The Sun has not risen, and Venus shines in the sky, in its unusual light.

The morning quiet of the Center for Deep Space Communication was broken by the sound of the siren and the automatic equipment slowly put into motion two receiving antennas. /49

The 16-meter parabolic cups of each antenna were trained on the remote Venus and, it appeared, listened for its voice.

But no, it is not Venus that they now hear, they hear the signals which Venera-5 has transmitted from a distance of 67 million kilometers to the Earth. The magnitude of the signals, attenuated

by the great distance in space, is so small that they cannot be distinguished from the radio interference of space itself, and only these antennas equipped with sensitive devices with parametric amplifiers, cooled by liquid nitrogen, can distinguish them.

How difficult this problem is may be illustrated by a comparison made by one of the designers of these antennas. "Imagine", he says, "that in the Black Sea a vat of boiling water was poured in, and we must use a special thermometer to measure how much the sea temperature has increased." They were solving a similar problem in the Center for Deep Space Communication when the descent capsule descended by parachute into the atmosphere of Venus.

On the morning of 16 May 1969 the communication session near the planet was begun. Onboard the station several commands were given which prepared the systems of the station to complete the final stage of flight. The signals confirming each command by the station were transmitted in 8 minutes to the Earth. The last radio communication session with the station Venera-5 occurred when the planet of Venus was approached, 2 hours before the entry into the atmosphere. It was begun based on a command from the computer at a time specified from Earth in the preceding communication session. For 8 minutes the control trajectory measurements were performed to refine the influence of the gravitational field of Venus and to introduce the necessary corrections into the ballistic calculations. Then telemetry information was transmitted on the state of the onboard systems.

The descent capsule of the station Venera-5 was separated from the orbital compartment before entry into the atmosphere of the planet at a distance of 37 thousand kilometers, and the station Venera-6 - at a distance of 25 thousand kilometers from Venus.

Radio communication with the orbital compartments of Venera-5 and Venera-6 was maintained up until they entered the dense layers of the atmosphere.

After entry into the dense layers of the atmosphere (9 hours 01 minutes Moscow time, 16 May 1969) the most complex stage of the flight began for the descent capsule of Venera-5 - aerodynamic braking.

With aerodynamic braking, the temperature behind the shock wave on the surface of the descent capsule in its frontal section reached 11,000°C, the kinetic energy exceeded the thermal energy and as a result the velocity of the descent capsule decreased in a short period of time from approximately 11 kilometers per second to 210 meters per second. After this, in a closely calculated period of time special sensors turned on the automatic system of the descent capsule which controls the operation of the parachute system and turned on the scientific equipment. The automatic systems first put into operation the drogue parachutes, and then the main parachutes, the radio transmitter antenna, the radio altimeter, and the scientific equipment. A smooth descent of the equipment into the atmosphere of Venus began along with the transmission of scientific data to the Earth. /50

Naturally, during those minutes when the descent capsule blanketed by plasma entered the atmosphere of Venus there was no communication with it and there was a great deal of concern among the operative groups and directors of the Center for Deep Space Communication. And there was great relief among everyone when the green light spot of the signal from the descent capsule appeared on the oscillograph tube and the solemn voice of the announcer was heard "There is the signal!".

The radio communication session with the descent capsule of Venera-5 began at 9 hours 2 minutes Moscow time. During all the time that the craft was descending, the communication with it was stable. The radio communication session lasted 53 minutes. At the time the communication with the descent capsule of Venera-5 ended, the external atmospheric pressure reached approximately 27 kg/cm^2 , which was the limiting value for the strength of the outer cover of the capsule. During the descent the temperature within the descent capsule changed insignificantly: from 13°C at the beginning of the descent to 28°C at the end of it. This points to the reliability of both the external heat protective cover, which protected the capsule from brief but extremely high thermal fluxes which arose during aerodynamic braking, and of the internal layer of heat insulation, which protected the capsule from heating in the atmosphere of Venus during the long period of descent by parachute, when the temperature of the atmosphere was approximately 300°C .

As the planet was approached and when Venera-6 descended into the atmosphere of Venus, the communication sessions were similar: the entry into the dense layers of the atmosphere of Venus by the descent capsule of Venera-6 took place on 17 May at 9 hours 05 minutes. The radio communications session during descent by parachute in the atmosphere of the planet was continued for 51 minutes.

INVESTIGATIONS ON THE FLIGHT TRAJECTORY AND IN CIRCUMPLANETARY SPACE

During the flight along the Earth-Venus trajectory, the automatic stations Venera-5 and Venera-6 performed measurements of solar and galactic cosmic rays and investigated the interplanetary plasma and the standard ultraviolet solar radiation.

The equipment carried on the orbital compartments of the station for measuring cosmic rays made it possible to record protons

with energies from 1 to 12 billion electron volts, and also protons with an energy greater than 30 million electron volts, and electrons with an energy greater than 0.1 million electron volts. As the measurements performed by Venera-5 and Venera-6 show, the total flux of galactic cosmic rays was lower than in June-October 1967 during the flight of the automatic station Venera-4, by approximately 15%, and by approximately 40% as compared with the data obtained by the stations Zond-3 and Venera-2 in December, 1965. This was /51 connected with the cyclic activity of the Sun and points to an increasing flux of nonuniform magnetic fields moving from the Sun.

During the flight of Venera-5 and Venera-6 a large increase was recorded in the intensity of solar protons fluxes with energies of 1-4 million electron volts, of which 12 were significant. The four increases in intensity were distinguished by a complex structure and long duration: each of them lasted no less than 7 days. The flux intensity greatly exceeded the level of the galactic background. This may be explained by the increasing activity of the Sun, manifested in a group of chromosphere flares of great strength occurring during this period.

Close to Venus new data were obtained about the structure of the circumplanetary plasma flows. It was previously established during the flights of spacecraft that the interplanetary cosmic space is filled with flows of plasma having velocities equalling several hundreds of kilometers per second. The plasma flows move from the Sun, and they thus obtained the name of the solar wind. This plasma is "magnetized" - it has a magnetic field with it.

The interaction of the solar wind with the magnetosphere of the Earth was studied extensively during the launches of artificial Earth satellites and spacecraft. However, as the plasma moves close to planets not having their own magnetic field, it was not known before the flight to Venus of the Soviet and American interplanetary stations.

The first abrupt changes in the plasma concentration, connected with a simultaneous change in the magnetic field strength in the vicinity of Venus, were observed 18 October 1967 by means of a charged particle trap and a magnetometer carried on the Soviet station Venera-4. Fluxes of interplanetary plasma were also recorded on Venera-5 and Venera-6. The largest volume of information was obtained by means of traps on the station Venera-6. As the station approached the planet, recordings were made of the changes in the magnitude of the fluxes and the plasma, which was characteristic for the region in which the solar wind passes over Venus. Thus, a front where changes in the plasma flow occurred was observed at a distance of about 28 thousand kilometers from the surface of the planet, and the station Venera-4 intersected this front at a distance of 19000 kilometers from the surface of the planet. This may be explained by the fact that the stations Venera-5 and Venera-6, just like Venera-4, descended on the night side of the planet, but far from the terminator, the boundary between day and night. Therefore, the intersection of the front of an abrupt change in the stream of charged particles occurred at a great distance from the planet.

Photoelectric photometers for measuring scattered ultraviolet radiation in the vicinity of the planet and in the interplanetary medium, carried on both stations, showed that, just as was observed during the flight of Venera-4, the radiation intensity in the atomic hydrogen line increased as the planet was approached. The results of the measurements were used to calculate the density of atomic hydrogen at distant regions of circumplanetary space. It was found that the first indications of a hydrogen corona appeared at a distance of 25,000 kilometers from the center of the planet, /52 and at a distance of about 10,000 kilometers the density of the hydrogen corona equaled approximately 100 atoms per cubic centimeter.

(Caption page 52): Data from measurements performed by Venera-6 in the atmosphere of the planet.

INVESTIGATIONS IN THE ATMOSPHERE OF VENUS

The basic purpose of the automatic interplanetary stations Venera-5 and Venera-6 was to continue the studies of the chemical composition and parameters of the atmosphere of Venus, first initiated by Venera-4 in October, 1967. For this purpose, the descent capsules of the automatic stations carried: systems of temperature and pressure sensors designed for different measurement ranges; gas analyzers for studying the gas composition of the atmosphere; a densimeter for measuring the density of the atmosphere and photocells for measuring the illumination in the atmosphere of Venus.

The gas analyzers measured the content of carbon dioxide, oxygen, water, and nitrogen together with inert gasses at two different levels above the surface of the planet. Consequently, the measurements were performed at different pressures and temperatures. The composition of the atmosphere was analyzed upon commands issued by the onboard computers. Out of the numerous possible methods of determining the composition of the atmosphere, the simplest and most reliable physical-chemical methods were used, based on well studied reactions having high selectivity.

The system of sensors for measuring the temperature and the pressure consisted of resistance thermometers and manometers of the aneroid type.

The mutual overlapping of the equipment measurement ranges made it possible to control the correctness of the measurements and their high reliability. To measure the atmospheric density, a device of the tuning fork type, whose operational principle was based on a change in the oscillation amplitude of a certain frequency

(Caption page 53): Venera-4 and Venera-6 passing through a shock wave.

as a function of the surrounding medium density, was used.

Photoelectric sensors were used to measure the illumination in the atmosphere of the planet. These sensors were designed to record the radiation in the visible and near infrared region of the spectrum with a threshold sensitivity of 0.5 watts per square meter. This illumination value approximately corresponds to illumination on the Earth during twilight. /54

One advantage of all of these devices is the simplicity of their construction, low weight and ability to operate reliably at high pressures and temperatures.

Radio altimeters of a decimeter range were carried on the descent capsules. The operational principle was similar to the operation of airplane altimeters. The radio altimeters were used to determine certain fixed values of the distance to the surface of the planet during the descent. The scales of fixed values of the altitude, which could be recorded by the radio altimeters, ranged from 50 to 10 kilometers. This selection of the operational range of the equipment was based on data obtained from Venera-4 and preliminary calculations of the expected moment of time and the altitude at which the parachutes opened. All of the scientific measurements were performed during the parachute descent of the station.

The first test of the atmosphere in order to analyze it on Venera-5 was performed immediately after the opening of the main parachute, when the pressure was about 0.6 kg/cm^2 , and the temperature - about $+25^\circ\text{C}$. The second test was taken at a lower altitude when the pressure was about 5 kg/cm^2 and the temperature was about $+150^\circ\text{C}$.

The gas analyzer on Venera-6 also made two tests of the atmospheric composition of Venus at different altitudes. The first sample was taken at a pressure of about 1 kG/cm^2 when the temperature was approximately 60°C ; the second - when the pressure was 10 kG/cm^2 and the temperature - $+225^\circ\text{C}$.

The results of the investigations of the atmospheric composition of Venus, performed on the automatic stations Venera-5 and Venera-6, confirmed and defined the data obtained previously on Venera-4. It was now found that the atmosphere of Venus almost entirely consists of carbon dioxide and contains elements of nitrogen, water, and oxygen. The carbon dioxide concentration was 93 - 97% (on Venera-4 it was $90 \pm 10\%$). The content of nitrogen, along with inert gases, was 2-5%, and the amount of oxygen did not exceed 0.4%. These results closely coincide with measurements of Venera-4, which showed that the nitrogen in the atmosphere of Venus is less than 7%, and oxygen is about 0.5%. The content of water vapors at a level of altitudes corresponding to a pressure of 0.6 kG/cm^2 is from 4 to 11 milligrams per liter. The measurements performed in 1967 by Venera-4 showed that at a pressure of about 0.6 kG/cm^2 there was from one to eight milligrams of water vapor in one liter of atmosphere. This points to the absence of saturation of the atmosphere of Venus by water vapor at the altitudes where the measurements were performed.

On the average, the telemetry commutator of the onboard radio equipment interrogated the temperature and pressure sensors every 40-50 seconds. More than 70 pressure measurements and more than 50 temperature measurements were carried out as each piece of equipment was lowered by parachute. The temperature and pressure of the atmosphere of Venus were measured within an accuracy of several per-c .nts throughout the entire sounding interval. /55

The stations Venera-5 and Venera-6 probed the atmosphere in regions where the temperature changed from approximately 25 to 320°C, and the pressure, from 0.5 to 27 kG/cm². The altitudinal temperature change in the measurement interval differed little from an adiabatic change. In 1967 Venera-4 performed measurements in a region where the temperature changed from 25 to 270°C. A pressure change from 0.5 to 18 kG/cm² corresponded to this region.

On the basis of results of measuring the temperature, pressure, and chemical composition, calculations were made of the regions in which the equipment was lowered into the atmosphere of Venus, and in which measurements of the atmospheric parameters were performed from the time the main parachutes opened. For Venera-5 this region covered 36 kilometers, and for Venera-6 - 38 kilometers.

The difference in the altitudinal values recorded by the radio altimeters at the beginning and end of the descent satisfactorily coincided with segments of the path traversed by the equipment during descent by parachute. The regions in which the descent capsules descended were calculated, based on the condition of atmospheric hydrostatic equilibrium, near the measured values of temperature and pressure at times corresponding to the altitudinal readings obtained, and also using the aerodynamic characteristics of the equipment during descent by parachute.

The results of calculations made by two independent methods closely coincided.

The altitudes recorded on Venera-5 and on Venera-6 for identical values of temperature and pressure led to values which differed from each other by 12-16 kilometers. Based on radio altimeter data of Venera-5, a pressure of 27 kG/cm² corresponded to an altitude of 24-26 kilometers, and based on radio altimeter data of Venera-6 the same pressure corresponded to an altitude of 10-12

kilometers. This evidently related to the great unevenness of the relief, since the descent took place over different regions of the planet surface which were hundreds of kilometers from each other.

The stations Venera-5 and Venera-6 performed their tasks and transmitted to the Earth data from deeper atmospheric layers than those of Venera-4. They made it possible by means of indirect measurements to greatly refine the chemical composition of the planet atmosphere and to obtain reliable values of temperature, pressure, and atmospheric density in an altitudinal interval of about 40 kilometers.

The results of these experiments confirmed that Venus has a very thick, dense atmosphere consisting primarily of carbon dioxide, and has very high values of pressure and temperature on the surface. If, down to the surface of the planet, the temperature changes according to an adiabatic law, then at the surface level determined by the radio altimeter on Venera-6 the temperature and pressure will be 400°C and about 60 kg/cm², respectively, and at the surface level determined by the radio altimeter of Venera-5 these values will increase - to 530°C and 140 kg/cm².

Photoelectric sensors carried on the stations did not record the illumination of the atmosphere of Venus on the night side above a threshold value of 0.5 watts per square meter. The one exception was one reading, noted on Venera-5, corresponding to a level of about 25 watts per square meter, which occurred approximately 4 minutes before radio communication was ended.

/56

The results of indirect measurements in the atmosphere of Venus performed on the Soviet automatic stations Venera-5 and Venera-6 are difficult to overestimate. The joint experiment was first carried out by two automatic stations which probed the atmosphere of Venus at two adjacent regions of the planet almost simultaneously.

(Caption page 56): Cross section of the atmosphere of Venus based on results of measurements by the automatic stations Venera-4, -5, -6, Mariner-5 and calculated data.

The unusual scientific data obtained provided a great amount of information about the puzzling planet, clarified the structure of its atmosphere and processes occurring in it.

"The completion of this complex experiment points to the high level of science and technology in the Soviet Union" - thus wrote the Varshavskaya newspaper "Tribune of the People".

"The Russians have performed extremely important scientific experiments. It is impossible to overestimate the scientific value of the information obtained. These data will help to solve some of the puzzles of Venus" - wrote the well known English scientist Bernard Lowell.

"The new victory of our science and technology in studying space was possible due to the heroic work of all the Soviet people". This was written in the welcome of the Central Committee of the Communist Party of the Soviet Union, Presidium of the Upper USSR Soviet and the USSR Soviet of Ministers. This scientific victory was completed when our entire country had new achievements of labor in building communism and observed the hundred year anniversary of the birth of V.I. Lenin - the founder of the Communist Party of the Soviet Union and the founder of a government of workers and farmers, which was the first in the world.". All the achievements of workers, technicians, engineers, and scientists of our country were dedicated to this celebration.

VENERA-7 — FIRST INFORMATION FROM THE SURFACE OF THE MYSTERIOUS PLANET

It is characteristic of Soviet science and technology to solve in a systematic and consecutive way any problems concerning it. While the workers in the factories built the stations Venera-5 and Venera-6, the designers worked on new variations of the descent capsule. /57

The automatic stations Venera-5, on 16 May 1969, and Venera-6 on 17 May 1969, continued the investigations of the atmosphere of Venus begun by Venera-4. Direct measurements of the atmospheric composition, pressure, and temperature were performed down to an altitude of 20 kilometers above the surface of the planet.

The data from these measurements provided a basis for creating a scientifically based model of the atmosphere of Venus. According to this model the average temperature on the surface of the planet is about 500°C and the pressure is somewhat greater than 100 kG/cm².

Under these conditions, the density of gases on the surface must be in all ten times less than the density of water.

However, in spite of the information obtained, it could not be asserted that the atmospheric parameters of Venus in the deep layers followed the model assumed.

A knowledge of the actual change of these parameters greatly assisted in obtaining an answer to several important problems regarding the nature and evolution of the atmosphere of Venus, including processes explaining the unusual thermal regime of the planet, which led to great differences in the structure of the atmosphere of adjacent planets - the Earth and Venus.

The most complex scientific-technical problem was placed before the designers and scientists, to build a device which would have the strength of a bathyscape, which could sustain a pressure of a kilometer of water and could thus resist the action of very high temperatures and could maintain the operational capacity of all the onboard systems when the device was lowered into the atmosphere of the planet and reached its surface.

This device was built by Soviet engineers and designers.

On 17 August 1970 the automatic station Venera-7 started towards Venus. On 15 December 1970 after four months of flight this station reached the planet, landed, and for 23 minutes transmitted scientific information from the surface of Venus.

The direct transmittal of scientific information to the Earth from the surface of another planet in the solar system was the first occasion this had happened in the history of space research.

The automatic station Venera-7 was developed on the basis of experience obtained by Venera-5 and Venera-6, and also on the basis of investigations of the atmosphere of Venus made by these stations.

The orbital compartment of the station and its systems, which had already been repeatedly checked in space, remained practically unchanged.

The descent capsule of Venera-7 was designed anew and designed for an external pressure up to 180 kg/cm^2 . Its heat insulation had to provide the necessary temperature regime within the descent capsule during aerodynamic braking during entry into the atmosphere of Venus, when the gas temperature on the nose surface of the descent capsule would reach $11,000^\circ\text{C}$ and when it would remain for 1 - 1.5 hours in the atmosphere of the planet at a temperature of $+540^\circ\text{C}$. /58

(Caption page 58): Flight path of the station Venera-7.

A change in the structure of the descent capsule led to an increase in its mass as compared with the descent capsules of the stations Venera-5 and Venera-6. The mass of the descent capsule of Venera-7 was about 500 kilograms. The total mass of the station was 1180 kilograms.

As noted above, the descent capsule of Venera-7 was designed not only to probe and investigate the atmosphere of Venus, but also to provide for operation of the scientific equipment immediately on the surface of the planet.

In this connection, the descent capsule of the station Venera-7 and its thermal insulation were redesigned based on the operational conditions for a pressure of 150 kg/cm^2 and a temperature of 540°C .

The construction of the parachute system of the descent capsule was greatly changed (as compared with the stations Venera-5 and Venera-6). These structural changes made it possible to pass through the upper layers of the atmosphere of Venus at a greater velocity and provided a more favorable temperature regime in the descent capsule in the region of descent not being studied (below 20 kilometers) and on the surface of the planet. The canopy of the parachute was made of heat-resistant material designed to operate at temperatures up to $+530^\circ\text{C}$.

There was a new element in the construction of the descent capsule - a shock absorber designed to decrease the overloads at the moment the descent capsule reached the surface of the planet.

The form of the descent capsule was changed also. In preceding stations it was similar to the shape of a sphere, but now only the internal strong housing designed for pressure up to 150 kg/cm^2

(Caption page 59): Descent capsule of the station Venera-7:
1- Mechanical damper; 2- Power housing; 3- Thermal insulation; 4- Commutation unit; 5- Heat exchanger; 6- Cover of parachute compartment; 7- Parachute; 8- Transmitting antenna; 9- Radio transmitter; 10- Aerodynamic damper.

had this form and the external housing had a circumeliptical form. The nose portion has so much greater dimensions than the upper covering of the parachute compartment, and it contains the aerodynamic stabilizer. /60

The hermetic compartment of the descent capsule - the equipment compartment - contains radio, telemetry and scientific equipment, the automatic processing units, power sources, heat control systems consisting of fans and heat exchangers, and a mechanical damper for eliminating operations of the descent capsule during its flight in the atmosphere of the planet.

The upper section of the descent capsule, above the equipment compartment, contains a parachute compartment, in which there is a transmitting antenna of the radio equipment, sensors of the scientific equipment, and an antenna of the radio altimeter in addition to the parachutes.

Separation charges are used to close the parachute compartment with a hermetic cover, which is fired after entry of the descent capsule into the dense layers of the atmosphere and braking at a velocity of about 260 meters per second, and the parachute system is put into operation.

FLIGHT TO VENUS

The automatic station Venera-7 was launched a year and a half after the launch of Venera-6, on 17 August 1970 at 8 hours 38 minutes Moscow time. At 9 hours 59 minutes, the last

stage of the rocket-carrier, operating for 244 seconds, imparted a velocity to the station which was somewhat greater than the second stage velocity, and Venera-7 was launched on a flight trajectory to the "morning star".

The problem of interplanetary flight, in spite of the fact that it is customary (man rapidly gets used to space flight) still involved enormous difficulties.

It is sufficient to recall several figures to prove the validity of these words. A station is launched from the Earth, which moves along an orbit with a velocity of 107 thousand kilometers per hour. After covering a distance of about 320 million kilometers, it must reach Venus, which has a size of 12,000 kilometers in all (in angular dimensions, one minute) and moves at a velocity of 125 thousand kilometers per hour.

If there were an error of 0.01% during the launch of the rocket, then it would miss Venus by 70 thousand kilometers. It is obvious that under these conditions it is almost impossible to have a station fly to Venus in a calculated amount of time and arrive at a given region of the planet's surface. Therefore, in the radio communication sessions trajectory measurements were performed which made it possible to determine the station flight trajectory parameters, the distance within an accuracy of 1 kilometer, and the radial velocity within an accuracy of 2 centimeters per second.

The position of Venus with respect to the Earth could be defined more accurately at the same time by means of radar equipment. Data from the trajectory and radar measurements could be used to calculate the initial data and to correct the trajectory. These data were transmitted along the radio channels onboard the station to a memory device of the control system. After this, in accordance with the flight program, onboard automatic equipment was used

/61

to carry out two trajectory correction sessions.

The first correction session was carried out on 2 October 1970, when the station was at a distance of about 17 million kilometers from the Earth, and the second was held on 17 November 1970, when the distance was 31 million kilometers.

As subsequent trajectory measurements showed, as a result of these two maneuvers, the station Venera-7 changed from a flight trajectory to an entry trajectory.

The intensity of cosmic rays was measured during the flight by means of a radiation dosimeter in the orbital compartment of the station. The value of these measurements lay in the fact that at the same time, by means of analog equipment, investigations were performed on Lunokhod-1 placed on the Moon by the automatic station Luna-17.

On 5 December 1970, when the station was 1 million, 300 thousand kilometers from Venus, preliminary operations began for the final flight stage - entry into the atmosphere of the planet.

For this purpose, on command from the Earth, the chemical sources of electric power of the descent capsule which until this time were in an uncharged state (in order to increase their reliability) were switched to the solar battery for charging. In addition, during the communication session on 12 December the thermal control system of the descent capsule was separated which maintained a temperature within the craft of $+10\text{--}\pm 20^{\circ}\text{C}$ during the approach. The descent capsule was cooled to -8°C to provide the most favorable temperature regime during descent into the atmosphere of Venus and landing on its surface. These operations were not carried out on the preceding Venera stations. These were new structural features, increasing the reliability and efficiency of the onboard equipment.

At a distance of about 600 thousand kilometers from Venus, the station fell into the sphere of attraction of this planet. From that moment on, the flight velocity of the station began to increase and continue to increase up until entry into the atmosphere.

On 15 December 1970, before the station entered the atmosphere of Venus, at 5 hours 30 minutes Moscow time, the 124th radio communication session was begun -- the session before reaching the planet. In this session, telemetry information about the state of onboard systems was transmitted to the Earth, and then the station and the narrow directional parabolic antenna were pointed toward the Earth.

All of the operations in this case were performed by means of automatic equipment on the station according to a previously formulated program.

After the 120-day flight, on 15 December 1970 at 7 hours 58 minutes 38 seconds Moscow time, when the station entered the atmosphere of the planet at an altitude of about 135 kilometers, the descent capsule was automatically separated from the orbital compartment. Communication with the station ceased. In order to provide absolute separation of the descent capsule from the orbital compartment, three independent programs were included in the separation system. The first was separation upon command from the programming equipment; the second -- separation upon command from the overload sensor (overloads arose during braking of the station /62 in the upper layers of the atmosphere of Venus); the third -- when the station is braked, the optical device loses the Earth from its field of vision and also the command for separation. Finally, this command may be given previously from the Earth and, if the improbable occurred and not one of these commands was given, then the separation took place smoothly. The bands holding the descent

capsule were not designed for a high temperature. They burned, and a special device pushed the descent capsule away from the orbital compartment. Under the influence of aerodynamic forces, the nose section of the descent capsule was turned towards the advancing flow, and was reliably held in this position by a special damping device.

During the aerodynamic braking, the descent capsule velocity with respect to the planet decreased from 11.5 kilometers per second to 200 meters per second, the temperature between the shock waves and the nose section of the descent capsule housing reached 11,000°C, and the overload had a maximum value of 350 units.

At 7 hours 59 minutes 10 seconds Moscow time, when the descent capsule was at an altitude of about 60 kilometers above the planet's surface, at an external pressure on the order of 0.7 kg/cm^2 , the cover of the parachute compartment was removed, and the parachute and the radio equipment of the descent capsule went into operation. The separation of the parachute compartment cover and the activation of the parachute system were duplicated by commands from different systems.

The descent capsule was in communication with the Earth.

On 15 December at 8 hours 34 minutes 10 seconds Moscow time, the descent capsule of Venera-7 landed on the night side of the planet 2,000 kilometers from the morning terminator.

At this time the distance between the Earth and Venus was about 60.6 million kilometers. The radio signal from the descent capsule (and from the station during the session as the planet was approached) covered this distance in three minutes 28 seconds. Therefore, the time indicated in the session as the planet was approached refers to the time the event was completed on Venus.

(Caption page 63): Temperature measurement performed by the station Venera-7.

RESULTS OF SCIENTIFIC INVESTIGATIONS

As has already been noted, during the flight of Venera-7 measurements were made along the trajectory of the intensity of cosmic rays. Solar flares and the dynamics of their development in space and in time were recorded by equipment carried on Venera-7, Lunokhod-1, the Earth satellites, and observatories on the Earth. Observations of a powerful chromosphere flare which began 10 December 1970 were of particular interest.

The pressure and temperature sensors carried on the descent capsule of Venera-7 made it possible to measure the pressure in a range from 0.5 to 150 atmospheres and a temperature from 25 to 540°C.

The rate at which the craft descended into the atmosphere of the planet could be recorded by the change in the radio signal frequency (Doppler effect) transmitted to the Earth from the descent capsule. For this purpose, very stable frequency generators /63 on the descent capsule were used, and several times during the flight they were calibrated and their readings were compared with a reference frequency. This made it possible to measure the descent capsule descent velocity in the atmosphere of the planet with great accuracy. The path distance traversed was determined from the time of descent.

After the descent capsule landed on the surface of Venus, equipment on the Earth continued to receive signals for 23 minutes. The magnitude of the signal received after the landing was 100 times less than during the landing. This could be explained by the deviation of the axis of the descent capsule antenna from the direction toward the Earth (inclination of the capsule) after

landing. Due to a specially developed method and the use of electronic computers, it was possible to separate the useful signal from the radio interference and to decipher it.

As a result of processing and analyzing the telemetry information transmitted from the descent capsule during its descent and on the surface of the planet, it was established that information was transmitted from the capsule only about the temperature of the surrounding medium - the most important parameter of the atmosphere of Venus. As results of measurements showed, after the landing the temperature of the surrounding medium did not change during the entire time that the radio transmitter was in operation.

Based on the time of descent, velocity, and temperature change, the law governing the altitudinal change in temperature down to the surface of the planet was determined. It was found that the law governing the temperature change (in the measurement session) was close to an adiabatic law. This was of very great scientific importance for understanding other processes occurring on Venus.

The flight of Venera-7 represented the beginning of direct experiments on the surface of Venus. The most complex engineering problems have been solved - obtaining scientific data under conditions of unusually high pressure and temperature. The correctness of the structural solutions selected when building Venera-7 was confirmed.

The scientific results transmitted by the automatic interplanetary station Venera-7 greatly expanded our knowledge about the planet closest to the Earth. Soviet science and technology have taken a very important step in studying space and the planets of the solar system.

(Caption page 64): Flight diagram of the station Venera-8.

VENERA-8 — FIRST ON THE DAY SIDE OF THE PLANET

"Always forward, do not stand still, forward. The universe belongs to mankind."

These words belong to the famous Russian scientist, the founder of cosmonautics, K.E. Tsiolkovskiy. It is impossible to better characterize the Soviet program for studying the Moon, the planets and space.

On 27 March 1972 the station Venera-8 started towards Venus with a mass of 1184 kilograms. 117 days were required for its flight to the "morning star". Only once, on 6 April 1972, was it necessary to perform a trajectory correction to assure that the station land in the given region of the planet. This problem was more complex as compared with those which had to be solved by ballistics during the flights of the previous Venera stations.

The problem was complex due to the fact that it was first necessary to land the descent capsule on the illuminated side of Venus. This meant that there were requirements on the accuracy of completing all the flight maneuvers, since the boundaries of the calculated "entry corridor" along which the descent capsule had to move during the final flight stage during entry into the atmosphere of Venus were very close.

As we now know, the orbit of Venus is within the orbit of the Earth, and in the period of the closest distance between the Earth and Venus, Venus is located almost on a straight line between the Earth and the Sun. Therefore, for the observer on the Earth a large portion of the disc of the planet is not visible. It is located in the shade, and only the edge of Venus is illuminated. It was

necessary that the station Venera-8 land on this illuminated edge.

All the previous Venera stations made a landing only on the night side of the planet. Therefore, the boundaries of the "entry corridor" were calculated as follows: the lower boundary - from the condition of the maximum permissible overloads providing for the integrity of the descent capsule, and the upper - from the condition that as a result of aerodynamic braking in the atmosphere of the planet the descent capsule was "captured" by the forces of attraction of Venus, and it made a landing at the subEarth point. In this case, the problem of transmitting information was greatly simplified, since the Earth is always located at the zenith - in the "field of view" of the narrow directional antenna of the descent capsule. /65

During the flight of Venera-8, in addition to the above requirements, it was necessary to land at the illuminated edge of Venus and to land in a circle with a radius of 500 kilometers in all. The center of this circle had to be a distance of 300 kilometers from the center of the planet disc.

These additional requirements were predicated by the location of the landing (ballistic requirements) and the conditions of radio communication. In the case of landing on the edge of the sphere of Venus, the Earth would be at zenith and if the landing did not occur in the calculated region, it would be outside of the field of vision of the descent capsule antenna and it would be impossible to transmit information.

In order to meet all of the above conditions, the angle at which the descent capsule entered the atmosphere of Venus (with respect to the local vertical) had to be approximately 13° . If it were less, the descent capsule would land on the night side of the planet. If it were greater, it would "strike" the atmosphere and pass by the planet.

(Caption page 66): Landing diagram of the station Venera-8:
1- Separation of the descent capsule from the orbital compartment;
2- Stabilization and aerodynamic braking; 3,4- Removal of cover
and beginning of action of parachute system; 5- Beginning action
of drogue parachute; 6- Beginning action of main parachute; 7- Open-
ing of altimeter antenna; 8- Separation of parachute.

How complex it was to solve this problem becomes clear, if we recall that at the moment that Venera-8 left the Earth, the distance between the planets was ~ 125 million kilometers!

It must be noted that the accuracy of ballistic calculations and the performance of these calculations were astounding. The space "sharpshooters" had to land at a given point of a ten kopeck coin, moving at a velocity of 60 kilometers per hour at a distance of 80 meters from the indicator.

Passing over 300 million kilometers on its space flight, the automatic station Venera-8 reached the vicinity of Venus. During the entire flight time, the station was in a regime of constant solar orientation (except for the trajectory correction session and individual communication sessions, when the transmission took place through a narrow directional parabolic antenna in order to increase the volume of information transmitted), which provided favorable operational conditions for the solar batteries and the thermal control system.

For several days before the station entered the atmosphere of Venus, radio communication sessions were held in which the equipment compartment was cooled along with special equipment - heat absorbers in order to decrease the heating rate of equipment located in the equipment compartment and to thus increase the duration of its operation, as well as the time of investigations in the hot atmosphere of the planet and on its surface.

At the same time the batteries of the descent capsule were 167 charged, the operational status of the scientific equipment radio devices was checked, and a check was also made on the thermal control systems and other auxiliary systems of the descent capsule.

As was shown by the data from the radio telemetry information, the reserves of electric energy in the batteries corresponded to the calculated value, and all of the onboard systems of the descent capsule operated normally.

At a distance of about 500 thousand kilometers from Venus, the force of attraction became predominant, the station flight velocity increased, and it was 11.6 kilometers per second when the station entered the atmosphere of the planet.

On 22 June 1972, before the station entered the atmosphere of Venus, a radio communication session was held, in which trajectory measurements were made in order to define more precisely the moment of entry and to correct the operation of the auxiliary equipment on Earth. Scientific information was transmitted about the conditions in space near the planet, data on the operation of the onboard systems of the station, and preparations were made to separate the descent capsule from the orbital compartment. At the same time as the radio communication sessions with Venera-8 (during the flight only 86 sessions were held) radar measurements of the Earth-Venus distance were made. As a result of these measurements, a great divergence was found (more than 500 kilometers) between the actual and calculated (determined according to classical, generally assumed laws of mechanics) positions of Venus at the time of measurement. These measurements made it possible to determine precisely the location of Venus at the time the descent capsule entered the atmosphere of the planet within an accuracy of ± 20 kilometers and the entry time within an accuracy of 100 seconds.

At ten hours 40 minutes Moscow time (in accordance with the calculations) the descent capsule was separated with a mass of 495 kilograms from the orbital compartment. Then for 53 minutes the orbital compartment and the descent capsule carried out separate flights.

At 11 hours 33 minutes communication with the orbital compartment ended. This meant that the orbital compartment and the descent capsule had entered the dense layers of the atmosphere. Only their fates were different.

After it had launched the descent capsule into the atmosphere of Venus, the orbital compartment was destroyed. The descent capsule, equipped with a composite improved heat shield, penetrated the incandescent atmosphere of Venus. The aerodynamic braking of the descent capsule in the atmosphere of the planet was continued for 18 seconds. The kinetic energy changed into thermal energy (the velocity changed from 11.6 kilometers to 250 meters per second, and the gas temperature in the nose section of the capsule increased to 12,000°C), and under the influence of the overloads the weight of each component increased by a factor of 335!

After braking in the atmosphere of Venus on command (either from the overload sensor at a value of $g = 2$ units on the descending branch, or from the computer) the cover of the parachute compartment was removed, the drogue parachute was introduced, and then the main parachute - 70% of which was reefed - was used for 11 minutes to descend to an altitude of 30 kilometers. At this altitude the reefing of the parachute was recorded at 11 hours 45 minutes, and the descent capsule descended further with a completely open canopy.

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A pyrotechnic device removed the cover of the parachute compartment, activated the drogue and main parachutes, and removed

(Caption page 68): Descent capsule of the station Venera-8:
1- Mechanical damper; 2- Radio transmitter; 3- Housing of instrument compartment; 4- Commutation unit; 5- Aerodynamic damper; 6- Lower equipment frame; 7- Fan 8- Air channels; 9- Electric switch; 10- Upper equipment frame; 11- Antenna-feed equipment unit; 12- Pipeline thermal control system; 13- Antenna of supplemental transmitter; 14- Parachute compartment; 15- Transmitter antenna (main); 16- Cover of parachute compartment; 17- Drogue parachute; 18- Main parachute; 19- Radioaltimeter antenna; 20- Pyrotechnic unit for cover separation; 21- Telemetry unit; 22- Heat exchanger; 23- Heat accumulator; 24- Internal thermal insulation; 25- Master generator; 26- Commutation unit; 27- Programming equipment; 28- External thermal insulation; 29- Heat accumulator.

the strands of the main parachute after the landing.

If it is recalled that the braking temperature was above 12,000°C, and the temperature at the surface was about 500°C, it can be seen that it was not simple to produce reliable, thermally stable pyrotechnic equipment and a parachute system. Only designers who have made a parachute system know how many experiments must be performed until a material is found which can withstand the velocity head and the temperature of the atmosphere of Venus.

The designers recall that such was the case during tests on the Earth.

Investigations were made on samples of parachute material and the suspension line for their strength in a tank for testing temperature and pressure measuring equipment at a temperature of more than +500°C and a pressure of 100 kg/cm² in a medium of carbon dioxide. All of the experiments were completed successfully. However, when tests of these samples were made in a wind tunnel (tests in an incandescent stream of carbon dioxide at a flow velocity of 250-300 m per second) the material and the suspension frames were scattered and changed into dust. For a long time it was not understood what had happened.

(Caption page 70): Descent capsule of station Venera-8 on surface of the planet:

1- Auxiliary antenna; 2- Sensors of pressure and temperature of the atmosphere; 3- Sensors for illumination measurement; 4- Main antenna; 5- Auxiliary antenna (before separation); 6- Parachute after separation.

Only after the gas flow was isolated from the surrounding atmosphere were the experiments successful. The cause of the destruction of the samples was atmospheric oxygen which penetrated in small amounts into the stream of carbon dioxide, causing oxidation of the material and the suspension slings, which reduced their mechanical strength.

Thus, the descent capsule of Venera-8 was in the atmosphere of Venus. It had completed almost an hour of descent by parachute.

The orbital compartment with its equipment, which was repeatedly tested by space, remained practically unchanged (as compared with the station Venera-7).

In comparison with the refinements introduced into the parameters of the atmosphere of Venus by the station Venera-7, there was a great reduction in the calculated values of the braking load acting on the descent capsule, and the maximum temperature of the surrounding medium on the surface of Venus.

This made it possible to decrease the mass of the descent capsule housing and the thermal insulation and, due to a savings in mass, to install additional scientific equipment and special devices making it possible to increase the operational time of the equipment and the systems when located on the surface of the planet.

A decrease in the mass of the descent capsule housing had no influence on its strength. Just as previously, it could withstand

a pressure of 100 kg/cm^2 , a temperature of 500°C and a 100-fold impact overload at the time of landing.

Taking into account the new landing conditions on the "edge" of the sphere of Venus and on the illuminated side of the planet, the designers had to solve new problems.

The descent capsule of Venera-8 might not land on a smooth landing area. It might be on crevasses or on a narrow incline; it might be overturned with the parachute compartment below. In 71 these cases the signal from the highly directional antenna of the descent capsule could not reach the Earth, since even with a normal landing in the calculated region of the surface, the Earth could be at the edge of the field of the antenna pattern of the descent capsule antenna. It was not possible to expand the angle of the antenna pattern of the spiral antenna, rigidly attached to the parachute compartment, or to make the descent capsule vertical after landing, as was done on later Luna stations in terms of weight and structural considerations.

Therefore the descent capsule of Venera-8 carried a second auxiliary antenna, connected with the radio equipment by a special heat-resistant cable.

At the moment the descent capsule touched the surface, this antenna was ejected from the parachute compartment and it assumed a vertical position by means of 3 spring claws. This improved the reliability of the radio communications between the descent capsule and the Earth. When the parachute was extended, radio communication was maintained by means of a spiral narrow directional antenna on the descent capsule (during aerodynamic braking, when the descent capsule was blanketed with plasma, communication was impossible). After landing, when the auxiliary antenna was extended, the computer periodically connected the radio transmitter first to one,

then to the other antenna. Communication on one or the other antenna was stable.

The selection of the landing site of the descent capsule on the illuminated side of the planet was not arbitrary. Another hypothesis (as was indicated above) was advanced to explain the high temperature and pressure values on the surface of the planet. The validity of any hypothesis depended upon the answer to the question of whether the solar light penetrated the cloud layer and the dense atmosphere to reach the surface of the planet, and whether there was a temperature drop between the diurnal and nocturnal sides of the planet's surface between the equatorial and the polar regions.

Observations performed on Earth could not give an answer to the question of illumination of the planet's surface. With respect to the temperature drop, radio astronomical observations and theoretical calculations indicated that, due to the high heat capacity of the atmosphere - although a day on Venus lasted almost 4 Earth months - the day temperature drops, and also the drops between the equatorial and the polar regions, were small. It was necessary to give certain answers to the questions advanced.

Although it was not difficult to measure the temperature and pressure, measuring illumination was another matter.

The complexity of measuring the illumination is indicated by the fact that the equipment had to perform measurements in a very wide range of light fluxes and operate reliably in the hot and dense atmosphere of Venus. Analogs to this equipment did not exist in measurement technology, and had to be developed. As is known, the flight of the automatic stations Venera-4, 5, 6 established that the basic components of the planet atmosphere were as follows: 97% carbon dioxide, no more than 2% nitrogen,

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less than 0.1% oxygen and less than 1% water vapor close to the cloud layer. In spite of specific concepts regarding the composition and structure of the atmosphere of Venus, the problem of the composition and dimensions of the cloud layer has not been solved. As has already been indicated, several scientists had assumed that the clouds may contain compounds containing ammonia. If we use this assumption, we may expect to find small amounts of ammonia in pure form in the atmosphere of Venus at pressures and a temperature occurring at altitudes below 50 kilometers. Therefore the descent capsule of Venera-8 carried equipment for determining the presence of ammonia in the atmosphere of the planet. The operational principle of the equipment was based on the fact that there are chemical compounds which change their color under the influence of ammonia vapors. In this case, tetrabromophenol sulfoftalein - a fine grained powder of a yellow color which becomes blue under the action of ammonia - was used. A change in the color was recorded by the photoresistors. To eliminate random phenomena and to increase the equipment sensitivity, a bridge system was used which recorded the color change as compared with a standard (i.e., with a similar agent placed in an hermetic capsule).

An experiment investigating the physical-chemical characteristics of the planet surface was a new feature.

To determine the nature of the rocks, usually a complete chemical or mineralogical analysis was performed. However, for such investigations, it was necessary to sample the ground and to study it for a long period of time.

It was a very complex problem to perform operations in the unusually difficult temperature conditions of Venus and to create a mechanical device which could open the hermetic housing of the equipment and sample the soil and return it to the receiving compartment. In addition to this, complex equipment was necessary to

analyze the soil. These devices could not be carried on the station due to limitations of weight, power, and the time for the active existence of the equipment on the surface of the planet.

Therefore, another method was used to determine the nature of rocks on the surface layer of Venus. This method was based on the fact that several individual chemical elements - for example, radioactive elements such as uranium, thorium, and potassium - are found in a specific percentile relationship in each type of rock. Therefore, they are a kind of visiting card for a certain type of rock.

A gamma-spectrometer is a device making it possible to determine certain specific radioactive elements. This device has one enormous advantage. It does not have to go outside of the hermetic housing, since the gamma-radiation, emitted by radioactive elements in the surface layer, freely penetrates the housing wall and enters the spectrometer detector. Another favorable characteristic for the use of the gamma-spectrometer was the absence in rocks on Venus of radiation introduced by cosmic rays (due to the screening properties of the dense atmosphere of the planet). This radiation posed serious difficulties for performing similar measurements on other celestial bodies. /73

The gamma-spectrometer on Venera-8 turned on a scintillation sensor, a 60-channel amplitude analyzer (to obtain the spectrum), and an intensometer for integral recording of the gamma-quanta, which could measure the total intensity of gamma-radiation with an energy of 0.3 MeV.

To perform the calibrations under conditions on the Earth, the gamma-spectrometer was placed in an analog of the Venera-8 descent capsule, and measurements were made above outcroppings of rocks (in their natural stratifications) with a known content of uranium, thorium, and potassium. The calibration was performed on granites,

basalts, and other rocks. In addition, above rocks which had a small content of radio elements, dunites, a determination was made of the intrinsic background of the station caused by the gamma-radiation of natural radioactive elements in the form of micromixtures in the material of the equipment and construction of the station.

At 12 hours 29 minutes, on 22 July 1972 the descent capsule of Venera-8 made a soft landing on the surface of Venus, and for 50 minutes transmitted scientific information to the Earth. There was no other such event in history.

The designers had constructed it so that the scientific equipment, the radio equipment, and other devices on the descent capsule could operate for almost two hours, while the device was located in approximately 500-degree heat.

Naturally, the thermal control system, which removed external heat through the heat exchanger into space, which was used in the orbital compartment, could not be used here. In this case, the problem had to be solved by accumulating cold, approximately as occurred in the glaciers, which were covered with ice in the winter and which stayed cold in the summer due to the thawing. These accumulations of cold in the descent capsule were the devices themselves, the housings, and special equipment which accumulated a reserve of cold during the freezing sessions of the descent capsule, which took place for several days before the station reached Venus when the descent capsule temperature was reduced approximately to -15°C .

To improve the thermal regime within the descent capsule, special equipment was used - heat absorbers made of material with a high heat capacity. When the compartment was heated, they first took in a great amount of thermal energy and then maintained the

operational capacity of the descent capsule equipment for a long period of time. The air was mixed in the compartment by means of a fan.

Reliable operation of all systems and scientific equipment on the automatic system Venera-8 and its descent capsule was provided by careful preparations on the Earth under conditions which simulated real conditions as much as possible - in space, in the atmosphere, and on the surface of Venus.

RESULTS OF SCIENTIFIC INVESTIGATIONS

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The automatic station Venera-8 successfully completed its flight, and the program of scientific investigations was completely carried out. The basic purpose was to obtain an answer to new important questions regarding the physical-chemical characteristics of the atmosphere and surface of the planet.

The station Venera-8 carried scientific devices making it possible to carry out a wide range of studies of the interplanetary medium along the flight trajectory, in the atmosphere, and on the surface of Venus on its day side.

The radiometric equipment carried in the orbital compartment of the station made it possible to perform systematic measurements during the flight along the interplanetary trajectory of the energy spectrum and variations in the intensity of cosmic rays. The data from these measurements made it possible to determine how the dynamic processes develop in space which are caused by solar activity.

During the flight of the station there was an anomalous increase in solar activity. This phenomenon had a great influence upon the intensity of cosmic rays in different energy ranges, which was confirmed by results of measurements performed on Venera-8.

Four powerful solar flares were recorded against a background of an increase in solar activity. During these flares there was a sharp increase in the intensity of protons with energies greater than 1 million electron volts and 30 million electronvolts. There was also a great reduction in the intensity of galactic cosmic rays coming from the very distant regions of space.

Similar results were obtained during an anomalous increase in solar activity by equipment carried on Venera-7, Lunokhod-1, and Mars-2 and Mars-3.

Measurements of ultraviolet radiation, produced by the neutral atmospheric hydrogen scattered in interplanetary space, showed that in individual regions of interplanetary space the intensity of this radiation increased by a factor of 2-3. Measurements were made of the radiation intensity in a narrow range of the ultraviolet spectral region, primarily against a background of bright blue stars.

The overloads were measured during the aerodynamic braking of the descent capsule as it entered the atmosphere of Venus. The change in the overloads depends on the altitudinal density distribution. Therefore these measurements provided data on the atmospheric parameters above the level of the beginning of direct measurements.

Direct measurements of the temperature and pressure in the atmosphere of Venus, when the descent capsule of Venera-8 descended by parachute and after its landing, were carried out using pressure and temperature sensors located in the parachute compartment. These measurements were initiated after the removal of the parachute compartment cover and the opening of the main parachute, at an altitude of 55 kilometers from the surface. At the same time as the measurements were made of the atmospheric parameters, the onboard radio altimeter was used to measure the altitude, and these

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(Caption page 75): Data from measurements of temperature and pressure performed by the automatic station Venera-8 in the atmosphere of the planet.

measurements were continued during the descent.

In addition to this, the height above the surface of the planet was determined from calculations of the hydrostatic equilibrium conditions (taking into account the pressure and temperature measured during the descent) and from the equation of motion of the capsule by parachute (the calculations employed the aerodynamic characteristics of the parachute and the capsule determined in experiments on the Earth).

During the descent of the descent capsule, a determination was made of the radial velocity of the equipment with respect to the Earth using a master generator of the onboard radio transmitter by means of the Doppler frequency shift.

By knowing the radial velocity, it was possible to calculate the capsule descent weight and, by integrating the velocity, to obtain additional information about the height of the capsule above the surface. As a result of comparing the measured values of the height above the surface of the planet with the calculated values, and taking into account the drift of the descent capsule due to the wind, it was possible to establish the altitude drop of 4-5 kilometers, with an inclination of about 10-12°. The automatic stations Venera-5 and Venera-6 also established the unevenness of the relief, only the altitudinal drop was greater and was 10-12 kilometers.

An analysis of the data on the atmospheric parameters obtained from the flights of Venera-4,-5,-6,-7 and Venera-8 showed that there were no great differences in the altitudinal profiles of temperature and pressure on the nocturnal and diurnal sides of Venus.

The temperature and pressure measured at the landing site of Venera-8 were $470 \pm 8^{\circ}\text{C}$ and 90 ± 1.5 kilogram-forces per cm^2 , which is very close to the values obtained in the experiment on Venera-7, although the landing sites of the stations were 3 thousand kilometers apart. One was on the diurnal side in the zone of the morning terminator ($9 \pm 3^{\circ}$) - the station Venera-8 - and the other was on the nocturnal side of the planet. The results of these measurements confirmed the conclusion, based on results obtained from the descent capsule of Venera-7, that the thermodynamic state of gas in the atmosphere of Venus obeys an adiabatic law down to the surface, just as in the atmosphere of the Earth. /76

Based on these measurements, the conclusion must be reached that on Venus there is a vertical mixing of the layers in the atmosphere.

At an altitude of 46 kilometers the first sample of gas was taken for determining the presence of ammonia, and at an altitude of about 33 kilometers, another sampling was taken.

The results of these measurements pointed to the presence of ammonia in the atmosphere of Venus, whose volumetric content may equal 0.01 - 0.1%. Proponents of the presence of ammonia compounds in the cloud layer of Venus received confirmation of their hypothesis.

Based on this, it could be expected that in the upper layers of the atmosphere at relatively low temperatures ammonia must be combined with water, carbon dioxide, hydrogen chloride, and other gases in the atmosphere, with the formation of ammonia compounds (most frequently, white crystals which reflect the light well) which may be one of the components of the cloud layer of Venus.

The crystals formed begin to fall (like drops of rain or snow on the Earth), but - reaching the layers with a higher temperature - they are again decomposed into their components and are sublimated in the upper layers of the atmosphere. This may represent the cycle of gases on Venus. The presence of ammonia in the atmosphere may also point to the presence of volcanic activity on this planet.

As we already know, as the capsule descended by parachute, the radial velocity of the capsule with respect to the Earth was measured from the Doppler frequency shift of the master generator. The radio altimeter was used to determine the descent rate with respect to the surface of Venus. Knowing these two quantities, it was possible to determine the magnitude and direction of the wind velocity on Venus. The wind velocity represents the horizontal velocity component in a plane containing the vectors of the radial and vertical velocities of the descent capsule.

At altitudes of 53 - 46 kilometers, based on the measurement results the wind velocity was estimated at 100-50 meters per second; at altitudes of 40-24 kilometers, the wind velocity was less than 38-26 meters per second. At altitudes of 20-14 kilometers, there was a sharp decrease in the wind velocity. The velocity gradient was 4 meters per second per kilometer. On the surface and up to an altitude of 10-12 kilometers, the wind velocity was much less and was 0-2 meters per second. One characteristic must be noted: the wind direction at all altitudes was latitudinal - from the terminator to the diurnal side, i.e. in the direction of the eigen rotation of Venus.

In order to produce on the surface of the Earth a velocity head such as the wind produces on Venus at an altitude of 15-20 kilometers, on the Earth the wind would have to have a velocity of 50-100 meters per second!!

It is obvious that the winds on Venus have a great influence upon forming the relief of the planet and are one of the basic characteristics of the atmosphere of the planet.

Information about illumination in the atmosphere of the planet was obtained during the entire period of parachute descent and after landing. These unusual data indicated that part of the light flux /77 of the Sun in the visible spectral region reaches the surface of the planet, and there there is a great difference between the illumination in the daytime and at night. In addition, the data from these measurements indicated that the atmosphere of Venus attenuates the solar light.

As the measurements showed, at an altitude of 49 kilometers the illumination is 3600 ± 1000 lux, and on the surface it is 350 ± 150 lux. An unusual change in the magnitude of the illumination gradient must be noted: in the altitudinal range from 49 to 30 kilometers, it was 145 lux per kilometer, and in the 30-0 kilometer region, it was only about 34 lux per kilometer. The sharp change in the illumination gradient at an altitude of 30 kilometers may be caused by the border of clouds. An analysis of the illumination data makes it possible to estimate the visibility range on the surface as equal to 1 kilometer.

The first measurements of the illumination were performed when the angle of the Sun at the landing site of the descent capsule was $8 - 10^\circ$ i.e., it was morning on Venus.

The scientists awaited with impatience information on the physical-chemical properties of the surface of the planet. The first data on the dielectric constants and the density of the soil were obtained by analyzing the level of radio waves reflected by the surface and emitted by the capsule during descent. The results of these measurements showed that the dielectric constant

(Caption page 77): Calibrated spectrum of γ -radiation obtained over an outcrop of granite on the Earth.

of the soil surface was a little more than three units. This provided a basis for assuming that in the region of the descent the surface layer of the planet is very friable, with a soil density of a little less than 1 and 1/2 grams per cubic centimeter (more precisely, 1.4 ± 0.1).

However, the most unusual information was obtained from the gamma-spectrometer. It was turned on and performed measurements first during the parachute descent in the atmosphere of the planet and after the station had landed on the surface.

When the capsule descended in the atmosphere of Venus, three measurements were made of the total intensity of gamma radiation. One measurement was made after the landing. It should be noted that there was no great change in the intensity of gamma radiation during the descent. This points to the lack of radiation from short-lived isotopes. Measurements showed an increase in the total intensity of gamma-radiation. This was apparently due to the decomposition of natural radioactive elements contained in the rocks on the surface of Venus. The gamma radiation spectrum of rocks was measured while the station was in operation on the surface of the planet. The information from the spectrometer was transmitted to the Earth twice, making it possible to determine the content of uranium, thorium and potassium in the rocks on Venus. /78

Based on preliminary calculations, the rocks covering the surface at the landing site of the descent capsule of Venera-8 contained 4% potassium, $2 \cdot 10^{-4}\%$ uranium, and $6.5 \cdot 10^{-4}\%$ thorium, which was similar in composition and percentile content to granite rocks on the Earth. Under conditions on the Earth, this relationship of elements is characteristic for rocks which were first melted from

(Caption page 78): Spectra of γ -emission obtained after the station landed on the surface of Venus.

the center of the planet and underwent secondary changes due to the influence of different factors in the surrounding medium.

On Venus the rocks discovered had a density of 1.4 G/cm^3 , which corresponds to a porous rock. It may be assumed that the decomposition of crystalline rocks on the crust of Venus was not only mechanical in nature, but was also related to the decomposition process influenced by temperature, pressure, carbon dioxide and corrosive (at high pressure and temperature values) water.

Data on the chemical composition and properties of the soil represents a valuable contribution to the study of geology on Venus and the planets in the solar system. Direct studies of Venus have only begun. Subsequent experiments will determine the composition and properties of rocks in other regions of the planet and will qualify the processes occurring in the solid covering of Venus, and the nature of its evolution.

WHAT WE KNOW ABOUT THE SURPRISING WORLD OF VENUS

...That which seemed impossible throughout the centuries, yesterday was only a daring dream, today becomes a real problem, and tomorrow - it is solved.

S.P. Korelev

...Life is extremely persistent, unyielding. It can exist under conditions which differ from those on the Earth.

G.A. Tikhov

On 12 February 1961 the automatic station Venera-1 first started out on the unknown path toward the mysterious planet.

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Seven times after this the Soviet stations attempted to solve the riddle of Venus.

Out of the eight stations, six reached the planet, and five of them transmitted to the Earth unusual data from direct measurements on the properties and composition of the atmosphere, the first data on the characteristics and the composition of the surface, and about the illumination in the atmosphere and at the landing site of the descent capsule.

Studies of the upper layers of the atmosphere of Venus were made by the American stations Mariner three times from flight trajectories.

Radio astronomers made a great contribution to the investigation of the "morning star."

In the last 12 years, as a result of radioastronomical and direct investigations of Venus by means of space technology, scientists

have come to learn more about this planet than during the preceding century.

There are celestial bodies in space which can be studied by means of automatic spacecraft and directly by humans using manned spacecraft. For example, circumterrestrial space, the Moon, and possibly in the near future - Mars.

But Venus, due to the unusual conditions in its atmosphere and on the surface, has been for a long time the undisputed "domain" of automatic equipment. However, in spite of this, we can imagine that by means of future spacecraft having long lasting systems of autonomous cryogenic protection, we may land on the surface. What /80 could we see and what could we study based on present day knowledge about this planet?

Due to inverse rotation of the planet (this is one of the puzzles of Venus, which must be solved) in one year on Venus there are two days and the Sun rises in the West and sets in the East. The fact that the planet axis of rotation is not inclined to the plane of the ecliptic leads to the absence of seasons. One interesting phenomenon must be noted, which is connected with the characteristics of orbital motion of the planet, the eigen rotation around its axis, and internal tidal phenomena caused by the influence of the Earth - in the inferior conjunction one and the same side of Venus is always turned toward the Earth.

The temperature of the outer walls of our spacecraft would be in the temperature region of red hot iron - 500°C , and the pressure would be about 100 kg/cm^2 , as one kilometer deep in the ocean. The density of the air (if it can be called this) on the surface is 60 times greater than the density of terrestrial air on the ocean.

Under these conditions, when the temperature on the surface of the planet is higher than the melting point or boiling point of many elements found on the Earth in liquid or solid phases, they can change into a gaseous (water, sulphur, bromine, iodine, mercury and others) or a liquid state (alkali metals, tin, lead and others).

Chemical-analyzers carried on our craft would record the presence primarily of a carbon dioxide atmosphere (93-97% CO_2). There would be 7 - 3% of the remaining gases (nitrogen, oxygen, ammonia, chloride, and fluoride compounds, water vapor, and others). It could be expected that with a change in height the composition of the additional atmospheric components would change greatly. Actually, with a change in height (as our equipment shows) the atmospheric temperature decreases with a gradient of 8 - 8.5° per kilometer, and the vapors of admixtures located in the atmosphere would be concentrated at different levels, as occurs with water vapors with a temperature decrease. These water vapors precipitate in the form of residues, forming a "cloud" at different altitudes, and then are again sublimated entering a temperature region equal to the evaporation temperature (sublimation) of these compounds or elements. It is possible that this process may be much more complex. It may be assumed that the reactions of combination and decomposition occur with the formation of new substances or their components, as occurs with ammonia and its compounds. At comparatively low temperatures in the upper layers of the atmosphere of Venus, ammonia is combined with water, carbon dioxide, and hydrogen chloride forming most frequently white crystals of ammonia compounds, which begin to precipitate in the form of residues and, reaching a height with a higher temperature, are sublimated. For example, for ammonium carbonate, this temperature equals 60° and, consequently, its sublimation must occur in the atmosphere of Venus at a height of 47-48 kilometers (from the average level).

(Caption page 81): Data on composition of the atmosphere of Venus and the Earth.

In the lower regions there may be magnesium hydrates, sulfurous compounds, compounds of ferrous chloride and others. Consequently, the cloud layer of Venus is not uniform but has a complex, stratified nature. Based on photometric data, it may be assumed that '82 the lower edge of the clouds on Venus is located at an altitude of more than 30 kilometers. On the Earth the upper boundary of the clouds is located at 10 - 12 kilometers.

But now, what do the clouds consist of, what is their structure, what is the mechanism of their formation? As can be seen, there are still no precise answers to these questions, only assumptions. These questions await their solution.

It is apparently impossible to see the Sun through a cloud layer which is about 30 kilometers thick (the upper edge of the clouds is located at an altitude of 60-70 kilometers), although it is almost 50 million kilometers closer than from the Earth. Due to this, in the daytime, which lasts 60 terrestrial days, there are no shadows on the surface, and the illumination is like a very cloudy, foggy day on the Earth with a visibility of about 1 kilometer. Due to the great density of the atmosphere, there is very strong refraction of light rays in the atmosphere and it appears that in all directions the line of the horizon goes up, and we are on the floor of an enormous basin. In spite of the fact that a day on Venus lasts two months and a night lasts the same amount of time, daily fluctuations in the temperature due to the enormous heat capacity of the atmosphere of the planet are 12°C; between the pole and the equator the temperature drop is 18°C. The strongest temperature gradient is observed in the vertical direction, as on a mountain which is 5 kilometers high the temperature will be 40°C lower than at its base.

(Caption page 82): Model of the atmosphere of Venus based on measurement data obtained during the flights of the automatic stations Venera.

(Caption page 83): Change of velocity and illumination as a function of altitude (based on measurement data obtained from Venera-8).

Due to the temperature gradient in the meridional, equatorial, 784 and vertical directions in the atmosphere of the planet there are complex circulation flows in the horizontal and vertical planes. On the surface the velocity of the flows is small (based on data from Venera-8), 0 - 2 meters per second, and they pass from the terminator to the day side (toward the side of the eigen rotation of the planet). At altitudes of 45 - 55 kilometers the wind velocity is about 50-100 meters per second in the same direction. This may possibly be related to the four-day circulation cycle of the upper atmosphere which was established (in photographs of Venus) in the ultraviolet rays. The motion of the "ultraviolet clouds" is 60 times faster than the rotation of the planet itself. On the Earth a similar phenomenon is observed at altitudes of 150 - 400 kilometers, and the advancing rotation of the atmosphere is about 1.2 - 1.4 times more rapid than the rotation of the Earth. No explanation has been found for this phenomenon on the Earth. On Venus it is explained by the characteristics of heat exchange and planetary circulation on the level of the cloud layer.

Along with the equatorial circulation, there is a vertical current, but at slower velocities there are strong currents in the meridian direction.

In 1969 - 1972 at the Institute of Oceanology of the USSR Academy of Sciences, calculations were made of the "weather" on Venus. The results of these calculations are as follows. The atmospheric circulation of Venus is almost symmetrical with respect to the equator and develops due to temperature differences between the diurnal and nocturnal hemispheres. These differences are con-

stantly maintained due to the fact that the diurnal side of the planet is heated by the Sun and the nocturnal side is cooled due to the eigen radiation (a temperature gradient of about 12°C). The circulation is not symmetric either with respect to the axis of rotation or with respect to the Sun-Venus line: the region of the greatest heating approaches the evening terminator, and the coldest region is located on the morning terminator.

The system of winds is as follows: in the lower layers the gases forming the atmosphere of Venus flow to the warmest region. There, they rise upward and scatter in the upper layers, are collected in the "cold" region where they again descent downward. These motions encompass the entire planet: there are no large scale vortexes such as cyclones and anticyclones. A typical wind velocity somewhat exceeds 5 - 6 meters per second (on the Earth a typical velocity is close to 10 meters). However, taking the fact into account that the density of the atmosphere on Venus is 60 times greater than the atmospheric density of the Earth (on the surface) the wind load on Venus for typical winds corresponds to hurricane winds.

According to calculations, the vertical velocities of gases in the atmosphere of Venus reach values on the order of several centimeters per second (on the Earth they are measured by a few millimeters per second). The entire lower atmosphere of Venus (the troposphere) is in a state of conductive mixing: on the day side this is caused by heating downward and on the nocturnal side - by cooling upward due to eigen radiation. These theoretical calculations must be verified and refined, but they are close to the real picture of processes taking place on Venus.

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The change in the atmospheric parameters of Venus down to the surface (based on data from the Venera stations) is adiabatic, and indicates active mixing of the atmosphere caused either by

(Caption page 85): Photographs of the cloud layer of Venus obtained from the American spacecraft Mariner-10.

global circulation, as indicated above, or gravitational cellular convection. Thus, it may be concluded that the thermophysical properties of the planet atmosphere determine the thickness of its adiabatic layer and the maximum surface temperature.

New data on the dynamic characteristics of the upper atmosphere of Venus were provided by the American spacecraft Mariner-10 when it flew around the planet in February, 1974.

Photographs of the cloud layer of Venus obtained by this spacecraft using photo-television equipment through ultraviolet light filters indicated the presence of powerful jet circulation streams in the upper atmosphere of the planet, directed along the spiral from the equator to the poles. The division between these flows is the turbulent region called the "eye of Venus" formed at the subsolar point (in the equatorial zone), having a diameter of about 1600 kilometers.

It may be expected that thermal energy is transferred by means of the powerful currents from the equator to the poles, equalizing thermal balance of the planet. Thus, judging from the motion of the cloud cover, the velocity of these currents is estimated at the equator at 320 kilometers per hour, and at the poles - twice as fast! These currents move in a direction opposite to the rotation of the planet.

The cause of these powerful currents may be fluxes of solar plasma (solar wind) coming into immediate contact with the atmosphere of the planet, due to the absence on Venus of "a shield" from these currents in the form of a magnetic shield, such as the Earth has.

Three photographs which were made at an interval of 7 hours each illustrate the evolution of the air currents in the atmosphere of Venus.

The data obtained from Mariner-10 substantiates the theory of global circulation of the atmosphere of Venus.

We have digressed somewhat with these theoretical considerations from the conditions surrounding a craft on Venus. We have noted that on Venus there is enormous pressure (about 100 kg/cm^2 on the surface). It is unusual and astonishing! Two-thirds of the Earth's surface are seas and oceans. If the world's oceans were divided equally over the entire surface of the Earth, the average depth would be 3 - 3.5 kilometers, and at the base of the hydrosphere of the Earth the average pressure will be 300 kg/cm^2 (three times greater than the pressure on the surface of Venus). Thus, there is nothing unusual about the conditions existing on Venus, as compared with the Earth.

What will the surface be like at the landing site of our craft?

In order to verify the data obtained from Venera-8, we shall perform a landing where its descent capsule touched the surface of the planet.

The landing equipment of our craft sinks deeply down into the porous surface layer, whose density is about 1.4 grams per cubic centimeter. Based on the spectrum of gamma-radiation of rocks at the landing site, it was established that these rocks are similar to terrestrial rocks based on composition and percentile content of radioactive elements. It may be assumed that they were ejected from the core of the planet and then were subjected to secondary changes under the influence of the surrounding medium (mechanical action, temperature, pressure, chemical action of carbon dioxide

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and water which is aggressive at high temperatures and pressure). Whether we want to or not, we are forced to call attention to the reading of the atmospheric gas analyzer - 93 - 97% carbon dioxide. Why? What processes led to this composition? The terrestrial atmosphere contained tens of fractions of a percent. Why is it that in the atmosphere of Venus there is 1000 times less water than on the Earth?

Apparently, the reasons for the different conditions existing on these two planets, which are partially twin-sisters, must be found in their formation and evolution.

In the general opinion of scientists, the planets were formed as a result of accumulation (accretion) of solid particles in a cold protoplanetary cloud surrounding the Sun during the period of its formation. For only a short period of time the planets in the Earth's group retained a primary atmosphere, whose composition was similar to the protoplanetary cloud (hydrogen, helium, inert gases, particularly neon).

The primary atmosphere was almost completely lost (possibly with the exception of heavy inert gases). The atmosphere consisting of volcanic activity - carbon monoxide, water vapor, nitrogen - replaced it.

The fate of this secondary atmosphere depended on the chemical interaction with the rocks forming the planet, and with the phenomena of partial surface melting of the planet surface from the decomposition of gas molecules by ultraviolet radiation of the Sun, on the rate at which the lighter components of the atmosphere were volatilized in space, and finally on the action of the biosphere. What path was traversed by the evolution on the Earth and on Venus?

For the Earth, this may be represented as follows.

The main product of volcanic activity (as studies of volcanic gases have shown) is water. Approximately 10 times less carbon dioxide was liberated. There was 300 times less nitrogen. The occurrence of molecular oxygen in the atmosphere of the Earth is connected with the occurrence of plants on the Earth - those chemical combinations which remove carbon dioxide from the atmosphere, changing it into sedimentary rocks (such as limestone) and liberating into the atmosphere molecular oxygen, a gas which belongs specifically to the Earth.

Under terrestrial conditions, inert nitrogen has apparently not undergone particular changes. It must be noted that under terrestrial conditions carbon dioxide is not combined only by biological efforts. When there is liquid water in the rocks, reactions take place converting silicates into carbonates.

Taking the fact into account that the dimensions and mass of Venus and the Earth are very close, it may be assumed that their internal structures are similar, and therefore volcanic processes must have taken place in approximately the same way. /88

There is actually a similarity: for example, the amount of carbon dioxide liberated into the atmosphere of both planets during their evolution is approximately the same. The difference in the amount of water vapor is enormous.

What is the answer to this? In order to explain this phenomenon, there are two basic hypotheses.

One of them assumes that the lithosphere of Venus gave up the same amount of water as the Earth. However, the fact that in the upper atmosphere of Venus (in the mesopause) the temperature is

10 - 20° higher in its coldest region than in the atmosphere of the Earth, and the hard ultraviolet radiation of the Sun may penetrate farther than on the Earth, causing, on the one hand, a high rate of vapor passing from the lower layers of the atmosphere into the upper layers, their more intense decomposition (photodissociation) under the influence of ultraviolet radiation upon hydrogen and oxygen, and more active "elimination" of hydrogen (due to thermal motion it acquired a velocity which was greater than the second cosmic velocity) from the atmosphere into space. Due to the high temperature and chemical activity, oxygen is combined with other gases and solid material of the planet surface.

Thus, dehydration of the planetary atmosphere occurs.

As calculations have shown, if the average temperature on Earth rises by several tenths of a degree, in 100 million years the Earth would lose its oceans. From the point of view of geological history, this is a very short period of time. The other hypothesis stipulates that Venus was formed at once (without water). This is due to the fact that in that part of the primary protoplanetary cloud (where the formation of Venus occurred), due to its closeness to the Sun (and, consequently, a higher temperature) there were no ice particles, and consequently the volcanic gases included no water vapors. The choice between these hypotheses remains for the future.

The first hypothesis is corroborated by the presence of a hydrogen corona on Venus and a large amount of deuterium (due to a mass which is greater than that of hydrogen, deuterium is less mobile, it is more difficult for it to reach the second cosmic velocity and to penetrate the atmosphere of the planet, and therefore it accumulates in the corona).

What processes are responsible for the high temperature and pressure in the atmosphere of this planet?

It may now be stated with great assurance that much attention should be given to the greenhouse model and the model of extensive circulation of the atmosphere of Venus (which we discussed above). The possibility can naturally not be excluded that internal heat of the planet plays a decisive role in the thermal regime of Venus. But any model must emphasize the important role of separation on Venus which equalizes the temperatures between the day and night sides, between the equator and poles.

Now, how do we answer the question of the forms of life on Venus?

The question of life beyond the Earth is very intriguing for /89 a thinking human being. For centuries, many scientists have believed that we are not alone in space, and that beyond our planet - on other celestial bodies - there may be living beings.

At the beginning of our century the majority of scientists assumed that the occurrence of life on the Earth was a "lucky coincidence" which could not be repeated. They affirmed that there could be no life beyond the Earth.

Numerous attempts to solve this problem, in terms of our closest neighbors, the Moon and planets of the solar system, have usual ; resulted in the fact that, after obtaining data on the physical and chemical conditions existing on a celestial body, we have attempted to determine whether our organisms on Earth could exist under these conditions. After this, conclusions were reached regarding the possibility or impossibility of life on this celestial body. The drawbacks of this method are obvious. Specific forms of life are the product of the external conditions

under which they are formed and developed. The external environment and conditions represent the instrument which produces the organism. Thus, it is doubtful whether we can detect life which is identical to that on the Earth upon other planets. The problem must be formulated in a different way - during the process of evolution, could a complex form of matter be produced and developed which we call life?

During their existence, all of the planets have evolved. It is possible that during the past there were conditions favorable for the development of life which adapted to the outer conditions during its subsequent development.

It has now become apparent that the occurrence of life on the Earth is not a "lucky coincidence". This was a regular process, an inherent part of the overall development of the universe, where each consecutive stage was closely related to the preceding stage.

Our Earth shows a great adaptability of forms of life to external conditions.

At a depth of 10 kilometers in the ocean, where there is perpetual darkness and the surrounding pressure is 1000 kg/cm^2 , the living world is just as diverse as in the upper layers of the ocean.

In hot sulphur springs having a temperature of $70-90^\circ\text{C}$, bacteria live and develop and the spores are subjected to a temperature of 100°C ! Some forms of bacteria selected springs containing iron, others exist only on petroleum. On the northern slopes of the Earth numerous insects have been discovered on lichens with a dimension of 0.5 millimeters; they have developed and exist under conditions of negative temperatures.

Blue-green algae have developed and exist on rocks melted by nuclear explosions and contaminated with radioactivity. Their vitality is astonishing; they may be found at the highest peaks of the Pamirs and on the slopes of volcanoes after eruptions. When placed along with other living organisms in a hermetic vessel containing air and water and exposed to the Sun (i.e., a closed ecological system was produced), the blue-green algae illustrated that they did not depend on anything. After several years the life cycle ended. Only blue-green algae remained in the vessel.

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Under laboratory conditions, the lower forms of life and plants were subjected to low temperatures down to -253°C , with radioactive irradiation in various doses. Life triumphed again.

Scientists studying meteorites made very unexpected discoveries. In the meteorites they found organic compounds (vaseline compounds, bitumens, hydrocarbons of the paraffin series), crystallized water, and so-called organized elements, whose external form was similar to spore-like formations and certain unicellular algae.

However, there was very little of this. As a result of experiments, the American scientist R. Berdger discovered a fantastic fact. Using a particle accelerator, he bombarded a mixture of methane, ammonia and water cooled to -230° with protons. After several minutes, urea acetamide and acetone were discovered in the mixture - organic substances which are necessary for the synthesis of the more complex compounds. The conclusion was reached that in space, where there are numerous atoms of different elements irradiated by streams of radiation, more complex compounds may be formed, including amino acids which consist, as is known, of proteins - the basis of life. All of these facts make us look at Venus from a different point of view.

In the atmosphere of this planet there is an excess of carbon dioxide, and small amounts of nitrogen, ammonia, water, oxygen, and other compounds. During the process of evolution, in the upper layers of the atmosphere close to the clouds above Venus, where conditions are very favorable (from the point of view of the Earth), could not life develop in the form of an air plankton or in other forms? This is still one of the puzzling secrets of Venus, which faces scientists.

In the last decade, we have come to learn a great deal about Venus. However, Venus continues to constantly reveal new puzzles.

How wise was the great French philosopher D. Diderot, and how pertinent his thoughts regarding nature in general and Venus in particular: "Nature is similar to a woman, who loves to dress up and who, showing one part of her body and then the other under her dress, raises the hopes of her insistent admirers of sometimes knowing her completely."

TO VENUS FOR THE SAKE OF EARTH

The human mind has discovered many wonders in nature and will discover still more, thereby extending its power over her.

V.I. Lenin

Dialectics teaches us that everything in the world is inter- /91
related and interconditioned. The activity of the Sun directly influences the processes occurring in the space surrounding it, and affects the entire solar system.

Three planets - Venus, Earth, Mars - form the so-called Earth group of planets.

By studying these planets, by understanding the processes occurring in the atmosphere, on the surface and in the deep layers we can better understand those processes which take place near us on Earth, and clarify the path of subsequent evolution.

By comparing, for example, our data concerning the atmospheres of the planets of the Earth group, through an understanding of the characteristics of the phenomena which determine atmospheric movement and thermodynamics under the conditions of neighboring planets, we will be better able to describe and to predict the features of terrestrial meteorology, and in particular to compile a more exact weather forecast.

At the present time, great efforts are being devoted to studying the influence of mankind on the climate. One of the most important tasks of geophysics consists in learning to forecast theoretically the means by which a "regimen of dynamic equilibrium" can occur

on our planet as a result of deliberate actions or slight effects exerted by human economic activity. The practical importance of this task is obvious. Technology has developed so rapidly that already the question arises as to the future destiny of the excess carbon dioxide and fine dust entering into the atmosphere from the combustion of fuel in industrial concerns and in millions of operating motors. Might not the accumulation of carbon dioxide, after having stepped up the "greenhouse effect," lead to a catastrophic warming up of the climate as occurs on Venus, or, conversely, to a process of cooling off such as occurs on Mars at the time of dust storms.

Or another example - are the polar ice caps stable? Might not relatively weak thermal effects lead to their disappearance and to world-wide inundation, or conversely to their catastrophic increase, i.e. to a return of an ice age.

The atmosphere of Venus is a singular model of an atmosphere /92 maximally polluted by suspended particles and carbon dioxide. When we have deciphered the dynamics of the meteorological processes and the thermal balance of Venus, we can predict with confidence impending climatic changes.

Very many similar questions arise, and we are helped in answering them by automatic stations in space which penetrate into the very remote and inaccessible corners of outer space. Man is taking only the first steps on the road to exploration of the cosmos and a knowledge of the Universe. These steps should serve to aid man to understand his beautiful, azure planet, Earth.

But, while getting to know the Earth, man must not be changed into a ruthless plunderer of her natural riches - they are not infinite.

This fact should always be remembered. In recent years researches conducted by scientists both on the Earth itself and in outer space have forewarned us. Persons who have been in outer space speak about this matter. After his flight, the Soviet cosmonaut, V. Sevast'yanov, wrote: "And suddenly one understands that the Earth itself is a spaceship which is rushing into the limitless space of the universe, having limited resources and a relatively small crew - mankind.

The people of the Earth must cherish their planet, spend its resources intelligently, and live in peace in the name of the future of our own and succeeding generations."

For the sake of the Earth, progress and the welfare of mankind, Soviet automatic stations are pressing into the depths of space.

COLUMBUSES OF SPACE

This chapter is about the chief designers Sergey Pavlovich Korolev and Georgiy Nikolayevich Babakin. Two different characters, two different destinies placed at the service of a single goal.

Sergey Pavlovich Korolev was born in Zhitomir in 1906. His childhood years occurred during hard and stormy times - an imperialist war, revolution, civil war, intervention and victory of the Soviet power.

In 1924, Sergey Pavlovich Korolev completed the First Odessa Technical School and entered the Mechanical Department of the Kiev Polytechnical Institute.

In 1926, Sergey Pavlovich transferred into the evening division of the Moscow Higher Technical College and began working at an

aviation plant. Sergey Pavlovich took his industrial training in the Central Institute of Aerohydrodynamics, imeni N.Ye. Zhukovskiy which was directed by A.N. Tupolev. The latter also became the director of the degree program of Sergey Pavlovich.

Within the walls of the Moscow Higher Technical School imeni N.E. Bauman, the young Korolev attended lectures on interplanetary voyages and interplanetary machines, on the ideas of K.E. Tsiolkovskiy, about the rockets of F.A. Tsander, and about the sketches and designs of N.I. Kibal'chich. And these ideas found the way to the heart of Korolev; however, not at once, but much later. But already in 1931, Sergey Pavlovich had worked out a project for a glider with a rocket motor.

In the years 1927-1930, propeller-driven aviation had defined /93 its "limits" and the aspiration to fly higher, faster and further pushed scientists and engineers ever more insistently into the creation of new forms of motors.

In Moscow, in 1931, there arose a public organization attached to the Society for Assistance to the Defense, Aviation and Chemical Construction of the USSR: the Moscow Group for the Study of Jet Propulsion (Mos.GIRD). Its President was F.A. Tsander. In 1932 by decision of the Presidium of the Central Council of the Society, the scientific research and experimental-construction organization, GIRD, was created. On May 1, 1932 S.P. Korolev became the Head of the GIRD; prior to that time he was the President of the Technical Council of the GIRD.

In 1933 on August 17 and November 25 at the "polygon" Nakhabinp (below Moscow) the GIRDovites accomplished the first launchings of Soviet liquid fuel rockets, GIRD-09 and GIRD-X.

Already in these years Sergey Pavlovich displayed talent as an organizer possessing enormous energy and capacity for work, inflexible will, enthusiasm and single-mindedness, capable of inspiring the collective to solve complicated tasks.

In these years in Leningrad the Gasdynamic Laboratory (GDL) which was under the Military Scientific Research Committee of the Revolutionary Military Council of the USSR, was occupied with work on the creation of jet motors. The director of the work on liquid and electric rocket motors was V.P. Glushko.

To unite the cadres for the study of jet propulsion, both groups (GDL and GIRD) were merged and the Jet Propulsion Scientific Research Institute was created and S.P. Korolev was named Deputy Director of the scientific section. Sometime later S.P. Korolev became head of the department of Winged Rockets.

He created the winged rocket 212 with the jet engine ORM-65, operating on nitric acid and kerosene. The rocket was launched with the aid of a propellant booster. The first flight of the rocket took place on January 29, 1939.

In 1937 the engine ORM-65 was installed on the glider SK-9 constructed by S.P. Korolev, and the machine was called RP-318 (rocket glider).

Flight testing of the rocket glider RP-318 was conducted on February 28, 1940 by test pilot V.P. Fedorov. This was the first flight in the USSR in a machine with a rocket engine.

In 1946 S.P. Korolev was appointed to the post of Chief Design Engineer of the Experimental Design Office, and he was entrusted with the creation of an intercontinental ballistic rocket. Here in all its brilliance was revealed his many-sided

engineering and organizational talent, directed to the solution of a most complicated, complex problem. The problem assigned was solved on the eve of the 40th anniversary of the October Revolution. On August 22, 1957, Tass reported the launching of a long-range intercontinental multistage rocket.

But the plans of Sergey Pavlovich already reached further. On October 4, 1957 for the first time in the world the voice of an artificial satellite of the Earth was above the Earth.

In subsequent years S.P. Korolev created the manned spacecraft "Vostok" and "Voskhod", which for the first time in history performed space flights and man entered into outer space.

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A little more than two years transpired after the launch of the world's first artificial satellite of the Earth, and on January 2, 1959 the first space rocket departed toward the Moon. The second space rocket, which was launched September 12, 1959, delivered to the Moon the banner of the country of the Soviets, and the station "Luna-3", which set out for the Moon on October 4, 1959, photographed for the first time the back side of the Moon.

New systems and new space robots were created.

On February 12, 1961 the station Venera-1 set out for Venus. On November 1, 1962 the station Mars-1 was directed towards Mars. To work out new systems and equipment for the spacecraft, the special stations of the "Zond" series were created, which penetrated the depths of outer space and yielded new information.

On November 12 and 16, 1965, the stations Venera-2 and Venera-3, which proved the possibility of investigating the planets of the solarsystem, were launched. But Sergey Pavlovich did not experience the thrilling moment when the station Venera-3 placed on Venus the banner with the emblem of the Union of Soviet Soc-

ialistic Republics. Sudden death on January 14, 1966 took away the outstanding scientist and designer in the prime of his creative powers and daring.

Before the Motherland, the party and the government accorded high praise to the services of Sergey Pavlovich Korolev. He was twice awarded the title of Hero of Socialist Labor; he was a laureat of the Lenin Prize; he was decorated with many orders and medals. In 1958 he was elected to membership in the Academy of Sciences of the USSR.

Because of the enormous volume of work awaiting action by the design office of S.P. Korolev, work on space automata was transferred to the design office of Georgiy Nikolayevich Babakin shortly before the death of S.P. Korolev.

Georgiy Nikolaevich Babakin was born in 1914. At an early age he lost his father and was obliged to support his family. Therefore, having finished a partial intermediate school in 1929, he entered the radio courses of the Peoples Commissariat of Communication, which he completed in 1930, and at the age of 16 he began his career as a worker.

In 1937, 8 years after finishing an intermediate school, he took as an extramural student the examination for the ten-year secondary school and entered the correspondence division of the Communication Institute. From 1937 to 1943, Georgiy Nikolaevich worked in the Academy of Public Services, where he studied the design of automatic photoelectronic analyzers for the continuous control of the quality of drinking water and directed work on ultrasonics.

During the years of the Great Patriotic War Georgiy Nikolayevich transferred to design work connected with the creation of models of military technology.

The subsequent life of Georgiy Nikolaevich up until his death was devoted to questions of the development of aeronautical and rocket space technology.

From the middle of the sixties, he was the head of a design office where work was carried out under his direction regarding the development of space apparatus for the study of the Moon and the planets of the solar system.

The first soft landing on the Moon, the first artificial satellite of the Moon, the first delivery of lunar soil to the Earth by an automatic machine, the first Moon-walker, the first measurements in the atmosphere and on the surface of the Morning star - Venus, investigations of the red planet - Mars, these are the stages of the "cosmic life" of Georgiy Nikolayevich Babakin. /95

Georgiy Nikolayevich departed this life on August 3, 1971 in the prime of his creative powers when "lunakhod-1" was preparing to meet its tenth lunar dawn, when two automatic Mars stations were maintaining their course to the red planet, when there remained on the designer's desk unfinished projects for new space robots.

For outstanding services in the development of national space science and technology, for work on the investigation of the Moon and Venus with the aid of automatic space machines Georgiy Nikolayevich was awarded in 1966 the Lenin Prize, in 1968 the title "Hero of Socialist Labor" was conferred upon him, and he was given the title "Doctor of Technological Sciences." In 1970 he was elected Associate Member of the Academy of Sciences of the USSR.

The labor career of Georgiy Nikolayevich was marked by the award of the order of the Red Banner of Labor and medals of the Soviet Union.

The services of Georgiy Nikolayevich in research on outer space were highly esteemed by French scientists, and he was presented the diploma and the medal of the National Center for Space Research of France.

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We have become witnesses of the fact that the prophetic words of Konstantin Eduardovich Tsiolkovskiy have been realized: "Mankind will not remain forever on the Earth, but in the pursuit of light and space man will initially penetrate timidly beyond the limits of the atmosphere, and then conquer for himself all circum-solar space."

Man is penetrating ever more persistently into outer space, studying it and placing it at the service of his interests.

Soviet scientists are continuing the systematic investigation of Venus with the aid of space vehicles which began with the automatic station Venera-4 in 1967.

One important outer space experiment has been successfully completed. The automatic interplanetary station Venera-8 which was launched on March 27, 1973 reached the planet Venus on June 22.

For the first time in the history of astronautics, scientific investigations of the surface of Venus were conducted, and the parameters of the atmosphere of the planet were determined on its illuminated side.

On February 5, 1974, enroute to Mercury, the American space vehicle Mariner-10 flew past Venus at a distance of nearly 6000

kilometers, conducted scientific investigations and photographed the cloud layer of the planet.

The program of investigating the planets of the solar system by means of automatic stations is continuing.